Architectural design game: A serious game approach to promote teaching and learning using multimodal interfaces

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Abstract
The present article introduces and develops an educational tool as an interactive digital game for architectural design, allowing the architectural students to challenge their knowledge and experiences. The framework of this educational tool supports a serious open-ended game, which helps students get involved with the game through self-assessment and a multi-modal natural user interface, including gesture recognition and speech recognition in a familiar CAD environment without any right or wrong solutions. The students can immediately compare their game results with the architecture of iconic buildings and get familiar with the complexity of the design process through five different games in the initial version of this tool without the fear of being judged. According to the results of the questionnaire, this tool can simulate the design process, enhance its quality, and thus, assist the learners with developing their required skills with a wide variety of motivations and opportunities for engagement while helping them connect their experiences and activities to their learning and development in a meaningful way to fill the gap between their knowledge acquisition and knowledge application.

Keywords Interaction design · Early years education · Interactive learning · Human-computer interaction · Open-ended game · Interdisciplinarity
Throughout history, architectural design education has always been a unique design-based method (Ebenezer et al., 2021; Emam et al., 2019). Although the prime goal of schools of architecture has been to teach students the design process, there is a challenge between knowledge application and knowledge acquisition in a design studio (Saghafi, 2020). To reverse this negative trend, architecture students should be assisted with developing the skills that can help them manage their knowledge in the design process. However, which modern educational approach can help students for this goal? How can they think and design as an architect and manage this difficult task in multiple-aspect complex designs? What is the solution to enhance the students’ motivation and reduce their failure feeling during their education? Regarding these questions, modern architectural education should take advantage of the new student-centered approaches to improve students’ learning efficiency (Emam et al., 2019). In this vein, game-based learning method, known as a novel student-centered approach, can enhance the motivation for learning by turning the classroom into an enjoyable and engrossing environment, and consequently, increasing its effectiveness and efficiency (Anastasiadis et al., 2018; Ucus, 2015).

Games are increasingly used as easy-to-understand instruments (Flanagan, 2010). Most of them have been designed for entertainment goals. However, educational games, known as serious games, have been able to offer valuable experiences in the field of education and learning for all ages (Koupritzioti & Xinogalos, 2020). A serious game works on the interaction using entertaining factors to submerge learners in an active learning environment and encourage them to overcome challenges with immediate feedback. In order to achieve complicated learning objectives, various serious game structures like open-ended educational games can be employed (Stoerger, 2007). In general, open-ended games possess several pathways in a learning environment, which is less guided, offering a genuine and personally purposeful learning experience to students by involving them in problem-solving tasks (Spring & Pellegrino, 2011). On the other hand, serious games are growing in popularity among architects as means for education, design, and investigation (Dodig & Groat, 2019). With the participation of architectural students in a game as a free activity with an indefinite result, the feeling of failure can be remarkably reduced (Javid, 2014). Accordingly, the mechanism of serious games can be used to create motivation and concentrated balance in architectural education (Holenko Dlab & Hoic-Bozic, 2021; Mestadi et al., 2018).

Moreover, with respect to the motivations and issues of players and game spaces, serious games can enhance the design capability of students in achieving a deeper and more comprehensive understanding of challenges (Azriel et al., 2005). However, achieving a deep comprehension in learning means that learners can get involved with evaluating their learning and knowledge and the intended applications (Petersen et al., 2019). In other words, students can control and evaluate their learning trends in the educational process. The self-assessment helps students to collect a vast amount of information and evaluate their feedback on
the education process. It allows them to direct and control their learning, and consequently, make a bond between their activities and educational goals (Holgate, 2008; Sluijsmans et al., 2013). As a result, throughout this educational process, the students change over to active elements and obtain independent thinking (Fernandez-Antolin et al., 2020). In this way, by employing an open-ended game-based learning structure, as well as generating personal learning and self-assessment motivation (Verpoorten & Westera, 2016), architecture students can achieve a deep understanding of the design process under the supervision of their teachers.

Furthermore, studies of researchers have shown that an interactive environment increases students’ motivation and provides a better performance (Nataraja & Raju, 2013; Westera, 2005). The interactive mode in educational video games is known as a useful element in learning since it allows the human-computer interaction (HCI) to provide useful creative experiences (Hodhod et al., 2011). On the other hand, designers should simultaneously use their minds, hands, and eyes to design from an architectural standpoint (Lobel, 2009). Since observing, thinking, and creating are the main components of the architectural design process, an unpredicted event or movement by hands can reveal the possibilities and opportunities that were not previously observed by the eyes. This can allow the mind to achieve new alternatives (Teng & Johnson, 2014). Thus, an interactive natural user interface can help architectural students strengthen the connection between their hands, eyes, and mind, as well as increase their motivation throughout the design process. This interaction can be regulated by multi-modal natural interfaces, including the gesture and speech recognition of a human to offer a happy and rousing mood throughout the design process. In this vein, combining multi-modal natural interfaces and architectural applications, digital serious games can make students more engaged and interested in and motivated to learn through the design process.

In the context of architecture, serious digital games with the goal of improving architectural visualization have been a significant subtopic in design education. Coyne (2003) discussed a theoretical basis to evaluate how the properties of computer games coordinate with design activity in terms of variation and repetition. In another study, Woodbury et al. (2001) evaluated the influence of applying serious games developed for architectural design to investigate form at the preliminary design steps. Shiratuuddin and Fletcher (2007) carried out a study on architectural visualization and design, in which games helped the learners in the environment of a classroom. Yan et al. (2011) proposed a framework to integrate BIM into games and created a BIM-Game prototype, which combines gaming and Building Information Modeling with architectural visualization. Their research was aimed at extending the flexibility of computer games in building design education. Hence, while game-based learning has been shown to improve the learning of the design procedure, the previous studies have hardly provided sufficient details about the serious game’s implementation and architecture. Additionally, the previous studies rarely examined serious digital games using cutting-edge HCI technologies or collected data on students’ perceptions and emotions about the role of technology in the design process.

Therefore, to ensure the effective use of serious digital games with HCI technologies in the design process, more information is needed about how students enhance
their knowledge while playing. Moreover, in order to bridge the gap between knowledge acquisition and knowledge application, in the first step, this study has developed an interactive motivating educational tool as an open-ended digital serious game in the architectural design process. This tool, called Game of Design (GaoDe), has been designed with multi-modal natural interfaces to recognize the speeches and gestures using a motion controller and machine learning in a familiar CAD environment. The initial version of GaoDe consists of five different games of iconic buildings designed by known architects. Based on their knowledge and experience, students can play with their gestures and speeches, immediately compare their design results with the existing buildings in the real-life, and perform self-assessment. Thus, the learning process is conducted unintendedly using a valuable indefinite experience so that students can achieve active participation and more profound understanding in their learning process without the fear of being judged. In the next step, this study explores architectural students’ experiential learning processes while playing the GaoDe to determine the usability and utility of the game-based learning applications with HCI technology in the design process.

The main contributions of this paper are as follows.

1. Using a self-assessment approach, this study proposes a serious open-ended game that integrates design process and HCI technologies in order to bridge the gap between the students’ knowledge acquisition and knowledge application.
2. This study describes an empirical case of implementing a serious game with HCI technology in architectural design.
3. This paper provides the study results of the survey to evaluate the architectural students’ perception and experiences of a serious game with HCI technology during the design process.

2 Technical background

2.1 Human-computer interfaces

The Human-System Interaction (HSI), as a research area, is associated with developing technologies that enhance the relationship between humans and systems. With respect to the type of an applied program, such systems are also called Human-Computer Interfaces (HCIs) or, generally, human-machine (Kumar & Goundar, 2019). With the continuous advancement in information technology, natural human-system interactions have become very popular in different fields (Ren & Bao, 2020). In such conditions, due to their low flexibility, the conventional input devices, such as mouses and keyboards, cannot create interactions between humans and computers, as natural objects do (Westera, 2012). Therefore, in order for interaction between humans and computers, new natural methods, such as commands based on voice and body language, are being used in various fields (Tran et al., 2020).

Hand gesture recognition, as an interaction method between a human and a machine, deals with those gestures of the humans’ hands, which transfer meaningful thoughts and information to the computer. The gesture-based interaction allows
humans to control computers instead of operating them (Rehman et al., 2020). On the other hand, speech-based applications are among the fastest communication means in the HCI. Such applications employ a speech recognition system to estimate the most probable sequence of words for speech input. Therefore, automatic gesture and speech recognition has been an active area of research over recent decades since they are known as useful tools to create familiar, practical, intuitive, and natural interfaces (Kraljević et al., 2020). Moreover, the use of the HCI approach enhances the learning process and turns it into a happy and rousing process, although being invisible (Kamel Boulos et al., 2011; Qi et al., 2019). Studies confirm that users have found gesture- and speech-based interactions much more comfortable, in terms of both learning and utilization, since they allow the users to conceptualize the potential solutions faster and more effectively (Tunçer & Khan, 2018). On the other hand, the evaluation of the traditional video games indicates that the interaction in them is mostly through mice, keyboards, or joysticks. However, with the advance of technology, today, the use of methods in which hand gesture and speech recognition is a means of HCI is more common and more comfortable (Khalaf et al., 2019). The attractiveness of the virtual environment and offering new experiences for users throughout the games are the other advantages of such tools (Mustafa & Ismail, 2018).

In architecture, modeling their conceptual designs in the form of 3D models in the CAD environment, architects and students seek to achieve the product conceptualization and visualization and improve their designs (Chang et al., 2019). This process is adopted using conventional input paradigms, which are based on WIMP (Windows, Icons, Menus, Pointer), making the users tired and unmotivated throughout the process. However, by using more natural HCI methods, a better and more interesting interaction can be achieved in design and modeling (Rapp, 2020). According to the results obtained from recent studies, the learning and use of multimodal natural interfaces composed of gestures and speech for 3D design in the CAD environment improve the user’s performance (Khan & Tunçer, 2019; Nanjundaswamy et al., 2013). Nevertheless, the design of such systems requires interdisciplinary research methods that include knowledge in architecture, electronic engineering, computer science, and information processing.

In general, two gesture recognition approaches allow for the independent development of third-party developers. The first one is to use wearable sensors like gloves or motion sensors like Leap Motion Controller (LMC) (LeapMotion, 2014) to track the whole body of a user or his/her hands. The significant advantage of motion recognition devices is that they include an extensive range of possible motions precisely activated by a sensor array (Manolova, 2016). On the other hand, they are discrete pieces of hardware that should be carried by the user, which is considered a disadvantage (Alimanova et al., 2017). The second approach is to use HCI systems without any discrete hardware, which have received considerable attention from the research society with the goal of developing natural indirect relationships (Mazzini et al., 2019). Since gesture and speech recognition is the issue of detecting a pattern in the continuous stream of data, the concepts from time series, signal processing, analysis, and control theory can be used (LaViola, 2013). For this purpose, machine learning concepts are generally used since one of the major ideas of
machine learning is to provide the possibility to divide data into particular groups, which is of great importance in gesture and speech recognition.

### 2.2 Leap motion controller

Given their new contact-free input, the interaction based on motion sensors is getting very popular. They need no physical contact and allow humans to make relationships with computers simply. The devices, such as the Kinect controller (Yao & Fu, 2014) and LMC, pave the path for humans to adopt the hand gesture-based methods in the form of natural user interfaces with no need for wearable sensors. In particular, the LMC and Kinect have been found as a strong basis to design natural user interfaces for educational programs (Bachmann et al., 2018). The use of such devices in the interactive education approaches makes the virtual environment more attractive so that users can gain various new experiences. Furthermore, by using them, the 3D CAD environments for design can be enhanced and turned into spatial interaction environments, improving the designers’ performance (Bai et al., 2013; Huang & Rai, 2018; Song et al., 2014). The Kinect is capable of detecting different parts of the human body at a distance of one to five meters. Meanwhile, the LMC can detect the gestures of hands and fingers at a smaller distance and with higher accuracy (Brogårdh, 2007).

The information obtained by sensors (Fig. 1) is used to create symbols of two hands, which are easily accessible through a software development kit (SDK). The SDK of LMC deals with a wide range of applications and games. It allows third-party developers to take advantage of interfaces, rigged characters, and conventional hand animations simultaneously. LMC supports numerous platforms to implement new applications. One of these platforms is the Grasshopper (Rutten, 2014), a parametric plugin for Rhino CAD software (McNeel, 2008) introduced by David Rutten at Robert McNeel & Associates. Depending on the design context, it allows a designer to plug and unplug various functions through developed tools and operates as a graphical associative logic modeler and editor of algorithms (Goli et al., 2021). Therefore, by using the Firefly tool (Payne & Johnson, 2013) in the Grasshopper platform, the required numerical values can be received from the LMC sensor and displayed in the form of hand characters based on the values obtained in the Rhino

**Fig. 1** The Leap Motion system (Nam et al., 2014)
CAD environment. The following are some of these values: pinch distance, bone, finger, hand or arm location, hands or finger widths, the direction of members, state of gestures, and count of fingers pointing.

2.3 Machine learning

As an advanced technology over recent years, machine learning is a data analysis and prediction tool, which has widely been used in many fields (H. Zhang, 2019). Machine learning (ML) is a branch of artificial intelligence (AI) that enables a computer program to gradually improve its performance in performing a task using statistical methods. The performance improvement ability is obtained through experience (learning) with no need for explicit programming (Samuel, 2000). Nevertheless, the need for transforming the raw data to a proper representation through the handcrafted process of feature construction is among the barriers to the efficiency of conventional machine learning methods. Meanwhile, by automatically learning the presentations from raw data using a nonlinear combination of simple data transformation, deep learning has eliminated the mentioned barrier (Liapis et al., 2019). Over recent years, the perception of computer vision and deep learning has widely been applied for many applications in computer science and human-computer interfaces, such as speech recognition, gesture recognition, natural language processing, computer vision, and control of robots (Fang et al., 2020).

Convolutional Neural Networks (CNNs) are deep learning models applied on 2D inputs, such as time-series images or data. A CNN consists of several convolutional layers that remarkably help detect objects and patterns (Albawi et al., 2018; Guo et al., 2017). Therefore, by using the combination of neural networks and computer vision, the image features can be automatically extracted and used to learn from trained data. The CNNs have components that produce a hierarchy of complex features. These components include a sequence of 2D trainable filters (convolutions), nonlinear activation functions, and pooling operations on raw data. Another advantage of such neural networks is their transfer learning capability. This ability removes the need for relearning caused by training from scratch and preserves time and memory (Kouzehgar et al., 2019). The recent evaluations of the performance of CNNs in HCI have indicated that the use of these networks markedly improves the performance of systems (Deng, 2014). Since their success in the ImageNet competition in 2012, the CNNs have been considered the most marked method for almost entire speech recognition and vision tasks (Liapis et al., 2019). In fact, speech recognition is the first application in the field of deep CNNs that has achieved commercial success (Hinton et al., 2012). Sound events, which are intrinsic to human activities, have specific frequency bands and time lengths. These events emerge in different 2D data models (i.e., spectrograms) that can be transformed through the feature extraction process. On the other hand, the CNNs can classify 2D data with high accuracy. Therefore, many researchers of the sound recognition field use such networks as the major classifier for the spectrograms. The results of these studies have revealed the remarkable performance of this application (Cakir et al., 2017; Salamon & Bello, 2017).
Hence, studies have been carried out to develop CNN-based models for the classification of sound signal patterns. These models are used to recognize human activities in indoor (or interior) environments (Jung & Chi, 2020). The first version (V1) of the dataset for speech command was an innovation of Peter Warden, who later published the improved version (V2) on a similar dataset with more commands. The accuracy obtained for the first and second versions was 85.4% and 88.2%, respectively. This version includes almost 65,000 audio files in the WAV format with 30 different speech commands collected from a large population of humans. The duration of each of the files is one second, and the sample rate is 16 kHz in all samples of each file. Accordingly, each audio waveform includes 16,000 samples (Warden, 2018). The words composing the dataset for speech commands have wisely been selected, and most commands are suitable for applications of the Internet of Things (IoT). In order to assess the mentioned dataset, Peter Warden employed a CNN-based model for small-footprint keyword spotting and reported the basic results for both dataset versions (Sainath & Parada, 2015).

3 Implementation of GaoDe tool

3.1 Architecture and development

By developing an individual integrated serious game, the present study seeks to fill the gap between the knowledge acquisition and knowledge application of architectural students. Given the original elements of game-based learning, i.e., exploration and discovery learning, GaoDe offers an environment, which has no correct or incorrect solutions. However, the players should alter the issues or solutions to balance their knowledge through immediate feedback in a serious open-ended game (Ke, 2011; Squire, 2008). Regarding such challenges, learners have to mentally implement and make a comparison between numerous alternatives in the process of choosing their problems or solutions. The main game action is represented by such a mental practice with different integrations of design and self-assessment, which should enhance the knowledge in students through empowering the recognition in the problem-solving process (Brezovszky et al., 2019). As long as the students are not satisfied with their results, the design procedure does not stop. Thus, considering the decisions made during the game, the player personalizes his/her experience of the game. The immediate feedback motivates the students to be competitive with themselves rather than the others.

Nevertheless, by introducing the personal information to the tool, the learners may have concerns regarding the judgment of their activities by others that can significantly affect their desire to employ the tool for self-assessment. By paving the path for the boundless activity of students during design with no request for their information, this tool provides a mindset that encourages them to perform self-assessment. Moreover, while empowering them to experience interesting learning activities, it eliminates the fear of failure in them (J. J. Lee & Hammer, 2011). Thus, by benefiting from the self-assessment strategy, the GaoDe enhances the learning of content, as well as the meta-cognitive supervision procedures that
are critical for their academic and professional life (Biggs, 2004). In addition, in order to enhance motivation and provide more opportunities for self-assessment, in the initial version of the GaoDe, five types of games with different styles of five famous architects, including Brick Country House, Fallingwater, Dancing House, HOUSE III, and Capsule Tower, are considered, which allow students to immediately compare their design results with the existing buildings in the real-life. By taking advantage of game-based dynamics, this tool motivates learners to improve their learning and find solutions for problems, consequently helping them to recall particular aspects and keep few analytical chronologies that is enhanced in better balancing of their knowledge (Kadel et al., 2018).

Moreover, since the self-assessment is performed in the form of a serious game in a virtual world, the players should enjoy interaction with the system that helps them to feel that the system is useful and easy to use (Van Der Heijden, 2004). Accordingly, if the students find the system easy to use and effective in enhancing their knowledge, they will be more eager to employ it as an educational tool. Finding out that with each movement of hands, GaoDe can offer various new alternatives encourages them to utilize it for self-assessments in the design process (Sun & Zhang, 2006). Therefore, in order to eliminate the constraints and the need for commands in architectural applications, the natural multi-modal interaction between machine and human, which recognizes the hand and finger gestures, as well as sound commands, is utilized, enhancing the attention and motivation of the learners. By enjoying the natural multi-modal interaction, the students would comprehend that self-assessments are easy to learn and easy to use since through enjoyable experiences, they gain more positive perception of the related aspects (Sun & Zhang, 2006; Van Der Heijden, 2004). However, with respect to the HCI technique, in all five games, various interactions are considered to avoid repetitions and enhance the students’ motivation.

In recognizing the hand gestures, given the high accuracy and speed required for 3D coordinates in the modeling process and the adverse effect of hand gesture recognition in improper time or repeated or wrong recognition during the real-time process of the game, the LMC is used for the modeling. All values that LMC can detect, including the hand pinch distance, bone, finger, hand or arm location, hands or finger widths, the direction of members, state of gestures, and count of fingers pointing, are used in the game process for different functions of modeling. For instance, by clenching the left hand, and opening the right hand, and moving it around the left fist, the camera’s movement can be controlled in the environment, or by making the right hand closer to or further from the left fist, one can become closer to or further from the result designed in the game. By using this function in all games, the camera can be adjusted at different angles, and the hidden angles of the designed model can be evaluated (Fig. 2). Moreover, machine vision technology is also employed to carry out the required commands in the modeling process. A webcam and a CNN model of the number of hand fingers by Vasquez are used (Vasquez, 2017). In this stage of the GaoDe designing, the number of fingers being equal to one and five are respectively used for the temporary saving of the design in the game process and finishing the game immediately (Fig. 3).
Regarding speech recognition, due to the marked tendency of the society to develop an offline speech recognition system, which supports digital voice assistants and has no need for a cloud computing platform (Murshed et al., 2019), the light and practical model of Warden is used (Warden, 2018). The model is programmed using the Zhang speech recognition code (A. Zhang, 2018) in an offline mode. The unit words include “stop,” “off,” “on,” “right,” “left,” “down,” “up,” “no,” “yes,” and “go.” Two specific groups are also considered in addition to these words: The words “unknown” (the command not considered in the previous set) and “silence”
The yellow color is defined for the system to activate the sound commands using the OpenCV library. Once the webcam detects the yellow color, the user can send his/her sound command to the system. The command “Yes” is used to implement the game at its beginning, and the commands “Up,” “Down,” “Left,” and “Right” are used to change the different views during playing (Fig. 4).

Furthermore, students should be able to perceive their design results obviously and evaluate their design process. This self-assessment can be performed digitally in the intended CAD environment or physically according to the CAD platform (3D print). Therefore, GaoDe requires a modern design process using the multi-modal natural user interface in a familiar CAD environment for architecture students. It should be capable of supporting the modeling, scripting for the human-machine natural interface, digital display, and creating a special code to be read by a 3D printer. In other words, it should overcome the limitations of existing game engines on architectural design and visualization. Hence, the GaoDe tool takes advantage of multi-modal natural user interfaces, including speech recognition, machine vision, and LMC, in the Grasshopper platform.

However, a simple custom user interface can increase the readability and motivation of students toward using the game. Different options were evaluated to find which user interface could be imagined for the GaoDe tool that can encourage a student to use the game (Malkawi et al., 2019). The main focus was on ensuring that the players could quickly define their playing trend with no need to deal with the codes programmed in the Grasshopper and Python platforms. Therefore, after the game is started by students, two approaches are designed for interaction with them during the game using the Human-UI (Heumann, 2016) and Conduit (Miller, 2017). At first, using the Human-UI, a specific pop-up window is developed with visual analysis, providing a clean and responsive view by active updates to help the students at the beginning and during the game to control and choose the trend of their game without dealing with the Grasshopper environment (Fig. 5a). In this section, visual elements associated with each game are used in order to make better relationships between students and GaoDe. Afterward, using the Conduit tool, information is displayed in the Rhino environment that changes
in a real-time form throughout the game according to the information entered at the beginning of the game (Fig. 5b). This information can help the students with the self-assessment process and improve their performance. Figure 6 illustrates the processing framework’s flowchart of the GaoDe educational tool.

3.2 GaoDe’s games

3.2.1 Brick country house

Ludwig Mies van der Rohe is considered among the most effective architects and architectural theorists in the 20s century. He is known as the pioneer of modernism
in architecture, who searches for the nature of contemporary architecture and rarely works based on the architecture concept, which indicates the specific characteristic of his architectural activity. His specific style enjoys a clear definition of place, the idea of global space, a definite construction logic, and precise details. In a brick country house constructed in 1924, probably inspired by a drawing of Theo van Doesburg, he comes up with an open-roof design having free slabs located in walls (Stach, 2018). The brick country house is formed based on a geometric shape with a vertical angle and a combination of opposite horizontal and vertical directions by putting up interior walls (Fig. 7). The classification of the drawing of the house can be observed in the 3D architectural drawing shown in the perspective design. The cubic and composite blocks, which make up the main core of the building, have established an iconoclastic architectural style in terms of structure. As the cubic blocks with different areas and heights rise, their shapes gradually change while getting further from the building core and forming walls inclined toward the outside. Thereafter, the walls do not limit the architectural space anymore. In turn, the block design is the element establishing the connection between the inside and outside the building and somehow creates a communication space with nature (Gała-Walczowska, 2015).

The goal of designing the Brick Country House game is to improve the motivation of students for design in a 3D environment and increase their 3D perception by using self-assessment. The design is performed in a real-time form by displaying the brick country house, and students are assisted with the design in the environment in a more ordered form by defining a 3D cubic grade. At the beginning of the game, students face three long walls, between which they should design vertical blocks in three dimensions. Students can immediately evaluate and improve their designs by turning around the environment. The vertical blocks are formed by the orientation of one hand of the student. If the palm faces up, it can plot internal walls, and if it faces the horizon, the blocks of the internal spaces can be designed. Given the change in

![Fig. 7 Brick Country House project, Mies van der Rohe, 1923 (Steyn, 2017)](image-url)
the dimensions and mode of one’s palm, the block can have different dimensions. By showing a pointer finger to the camera, the block stabilizes in the GaoDe environment, and by showing the five fingers, the game finishes (Fig. 8).

3.2.2 Fallingwater

Frank Lloyd Wright is generally known as one of the greatest American architects. His name invokes magnificent images of architecture astonishment, connection with nature, and artistic success. He believes that a beautiful environment and objects enrich and enhance life (Muratovski, 2019). In the architectural creativity of Wright, from houses with vast plains to Fallingwater houses, the relationship between nature and architecture is considered obvious interior and exterior visual integration (Gudkova & Gudkov, 2017). The Fallingwater house, also known as Kaufmann residence, is a masterpiece of Wright that has brought about a creative integration of natural architecture and cubist elements (Ahangar et al., 2015). The integrated connection between the interior and exterior space has also been formed by the significant perception of the spatial structure composing the building. In fact, the overlaps are cantilevers with concrete reinforced slabs that come out of the building center at various elevations and directions (Fig. 9). This wisely combines the viewpoint of a person from outside the Fallingwater house design with the seemingly random nature, despite having a strong geometric order and structural logic (Gudkova & Gudkov,
The purpose of designing this game is to involve the students' visualization while playing. Therefore, unlike the Brick Country House game, the final style of the game is not displayed as real-time so that the students can challenge their visual perception. In this game, some cubist elements are used that emerge with the orientation and length of the student’s palm. By showing one finger to the camera, the element stabilizes, and the students can freely design other elements of the game. When the students are satisfied with the design by placing the cubes on each other, they can high-five the camera to finish the game and make the cubes form the Fallingwater house style. The concrete slabs and interior horizontal and vertical spaces of the Fallingwater house at the end of the game are formed with respect to the proportions of the elements and their orientation relative to the coordinate axes (Fig. 10).

3.2.3 Dancing house

Frank Gehry is a variety-seeking character. The specific characteristic of his works is the avoidance of Euclidean forms, geometric shapes, and perspective. It seems that unconventional and asymmetric shapes are the major priority for him (Bellone et al., 2017). Gehry creates a new architectural world that is committed to freedom of speech. This is superior to any other thing and simultaneously defines new boundaries that have not been governed by any other factor. For instance, the dancing house building (Fig. 11) encourages its audience to think as an artist when looking at a visual characteristic and ask themselves the question, “what happens when the uncontrolled realism and irregularity are combined” (Kerle, 2017).

The goal of designing this game is to involve the students’ perception with the design of soft curve forms using their finger gestures. The first and last fingers of both hands help students model their design so that by placing the first hand in front of the LMC, the size and location of the top of the building is defined, while
the second hand determines the building’s waist in a similar way. Afterward, depending on the space between the fingers of each hand, the buildings form various styles. Eventually, when students ensure the dimensions and location of the building design, they only have to lower the three middle fingers of their upper
hand to save the designed building. Then, the students can continue the design by creating other buildings besides each other (Fig. 12).

3.2.4 House III

In the case of considering only the amount of texts written about particular designs of an architect as a symbol of his/her proper effect on the architectural training and this specialized profession, Peter Eisenman and his studies on the house form have undoubtedly been the source of attractiveness and effectiveness all around the world (Major & Sarris, 2001). Such houses are of great importance in architecture history since they seemingly indicate the emergence of post-functionalism and post-humanism (Ostwald & Vaughan, 2009a).

House III was designed for Millers located in Lakeville, Connecticut, and finished in 1971. Like the first and second houses, this house is made of a coated wooden frame, and its facade is made of color plaster. In this house, an attempt has been made to create a physical environment with a limited set of combined and transformational rules. Among the formal works of Eisenman, the location of House III has resulted in proposing plans at an angle of 45°, which is different from the typical 90° orthogonal plan systems (Fig. 13) (Ostwald & Vaughan, 2009b). In House III, a random shape is inserted into the drawing, based on which a plane is formed at an angle of 45° relative to the ordering grid (Fig. 14). The two systems remain distinct, i.e., a rotating cube obviously overlaps with an orthogonal cube, where the geometries...
Fig. 13  Peter Eisenman, House III, 1969–1971 (EISENMAN ARCHITECTS, 1971)

Fig. 14  Peter Eisenman, House III, 1969–1971 (EISENMAN ARCHITECTS, 1971)
are not yet merged. The house is meant to produce a feeling of estrangement in its inhabitants (Lo, 2019; Major & Sarris, 2001).

Designing this game aims to make the students autonomous to design and receive different feelings of their design so that they can insert every two cubes arbitrarily at any angle relative to each other, perform a different design, compare them, and change them again. The design of each cube depends on the order of putting the fists (left and right) in front of the LMC. The students can immediately see their game and challenge it at different angles (Fig. 15).

### 3.2.5 Capsule tower

Kisho Kurokawa is a famous modernist architect who founded the metabolism movement in cooperation with a few others in the 1960s. He has carried out several major projects in Japan and turned into one of the most famous Japanese architects in the late twentieth century (Walliss et al., 2018). The Nakagin capsule tower, designed by him in Shimbashi, Tokyo, is an important symbol of modular architecture. The topology of the capsule tower is an idea inspired by theoretical topics raised by people, such as Archigram groups in Great Britain and the metabolism movement in Japan in the 1960s (Andrade et al., 2016). These projects were composed of structures that used building capsules, which could be plugged and unplugged from buildings, but it has not occurred in practice so far (Fig. 16) (Jablonska et al., 2018). The theoretical framework of these designs is a combination of architectural design
and natural progress. In this vertical building, 144 capsules are connected to two communication columns. The separate units have been designed such that they can replace new and moving units.

The target of designing the Capsule Tower is to involve students in the design at height rather than horizontal design. This game seeks to execute a random algorithm that can excite the students and apply rapidity of action to the game to some extent. The students should start the game with two fists and move their hands in different directions. At the same time, they can observe the design resulting from their hand gestures in the Capsule Tower style. When the students achieve their intended design, they can open their hands and look at and save their design from different perspectives. Otherwise, they can clinch their hands again and continue to the game-design (Fig. 17).

4 Methodology

4.1 Research design

As a major characteristic, a serious game should be accepted by probable players. It is a failure if they do not accept it. In addition, greater information on the students’ perception of a game through HCI technology in the design procedure is required to make sure that the serious game is accepted in architectural design education. Accordingly, a quantitative study was conducted to recognize the opinions of the architecture students regarding usability of the GaoDe and whether it supports them achieve better results compared to the traditional techniques used in schools (Oyelere et al., 2018). The developed learning tool was examined in January 2020 to investigate its utility in an actual classroom environment as a part of an empirical study carried out during the educational procedure at Pars University. A survey was performed on a sample to provide the empirical study with direct knowledge of

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Fig. 16 Nakagin Capsule Tower, Tokyo, Japan, 1972, idea vs. construction (Pérez, 2018)
reality and quick quantification of the outcomes (Feigin & Weisman, 1950; Stimson, 2014). The sample consisted of 41 first-year students, 24 males and 17 females, who had attended the design studio, a mandatory course in architectural design. Nevertheless, the students were notified that they were able to withdraw from the study at any time. Their rights were protected, and they were informed that their ideas would not be associated with their identities.

4.2 Data collection and analysis method

At first, the relevant topics were explained to the students of the design studio course as a part of the GaoDe tool according to the design study. In addition, the open-ended game-based learning, along with the main idea of self-assessment and the way it was employed in their learning procedure, were briefly introduced to the students. Then, they were provided with the GaoDe user guides and subjected to game-based learning using the GaoDe in their planned classes. Afterward, assessment sheets, including some questions, were given to the participants to investigate the performance of the learners and the effectiveness of the game throughout the quantitative research procedure. According to (Mesquida & Mas, 2018), the questionnaire consisted of 19 items that were arranged and structured in four subsets with respect to their topics in consistence with the IBM Computer Usability Satisfaction Questionnaire (Lewis, 1995) for evaluating usability and
utility characteristics of computer systems: the usefulness of GaoDe (5 items), evaluation of games (6 items), improvement in the learning (6 items), and satisfaction (2 items). A 5-point Likert scale, offering a combination of responses, i.e., “strongly agree,” “agree,” “undecided,” “disagree,” “strongly disagree,” was employed so that the participants could confirm their decided statements using them. A Microsoft excel sheet was utilized to analyze the questionnaire data. The common descriptive statistical values like mean and standard deviation were computed in the detailed data analysis to recognize the students’ attitudes toward the utility of the GaoDe tool in providing architectural education.

5 Results and discussion

As can be seen in Table 1, the answers are divided with respect to four validation aspects. The responses that strongly agree or agree with the statements constitute a larger portion, being more than 82% for the four studied aspects. It is notable that none of the questions received the lowest score (strongly disagree). In particular (Table 2), concerning the usability of GaoDe (A1–A5), the mean values of all questions were more than 4.0, therefore, being within the range of agreeing and strongly agreeing with more participants inclined towards the strong agreement, which can be due to its user-friendliness, ease of use, effortlessness, easy understanding, and proper interactivity through the design process. Similarly, concerning the “evaluation of games,” the participants gave very good scores to all five games of GaoDe. Most of the games (questions B1 to B5) had mean values of higher than 4.0, i.e., the students’ answers were within the range of agreeing to strongly agreeing regarding the involvement of the five games, indicating that the users had fairly positive opinions concerning the joyfulness and playability. Generally, such a strong attitude of students further ensures that GaoDe is easy to learn and easy to use, maintaining high performance for long-term engagement through the design procedure. Moreover, given the mean value and standard deviation being equal to 4.122 and 0.705, respectively, for question B6, the majority of the users reported pleasant experiences of self-assessment throughout the design procedure using the GaoDe tool (Sun & Zhang, 2006; Van Der Heijden, 2004). Nonetheless, the Fallingwater game (question B2) received a lower score compared to the other games in GaoDe, indicating the users’ tendency towards more immediate feedback, providing them

| Table 1 Experimentation groups |
|-------------------------------|
| Aspect                       | Strongly agree (%) | Agree (%) | Neutral (%) | Disagree (%) | Strongly disagree (%) |
| Usability                    | 32.68%             | 47.80%    | 17.07%      | 2.44%        | 0                    |
| Evaluation of game modes     | 32.11%             | 50.81%    | 15.45%      | 1.63%        | 0                    |
| Improvement in the learning  | 30.49%             | 51.63%    | 16.67%      | 1.22%        | 0                    |
| Satisfaction                 | 46.34%             | 42.68%    | 9.76%       | 1.22%        | 0                    |
| Aspect                      | Question                                                                 | Mean  | SD  |
|-----------------------------|--------------------------------------------------------------------------|-------|-----|
| Usability                   | A1 Are the graphical user interfaces of GaoDe user-friendly and easy to follow? | 4.171 | 0.729|
|                             | A2 Is the information provided through the guides comprehensible?          | 4.073 | 0.838|
|                             | A3 Does the use of GaoDe require low mental effort?                       | 4.049 | 0.697|
|                             | A4 Is the interactivity level suitable?                                   | 4.146 | 0.813|
|                             | A5 Is the GaoDe easy to use in the design process?                        | 4.098 | 0.726|
| Evaluation of games         | B1 Was the Brick Country House game engaging for you?                      | 4.195 | 0.706|
|                             | B2 Was the Fallingwater game engaging for you?                            | 3.878 | 0.802|
|                             | B3 Was the Dancing House game engaging for you?                           | 4.146 | 0.751|
|                             | B4 Was the House III game engaging for you?                               | 4.220 | 0.564|
|                             | B5 Was the Capsule Tower game engaging for you?                           | 4.244 | 0.725|
|                             | B6 Were GaoDe’s games appropriate for self-assessment?                    | 4.122 | 0.705|
| Improvement in the learning | C1 Did GaoDe attract your attention to design and keep you motivated?     | 4.073 | 0.677|
|                             | C2 Did interactive play assist you in the design process?                 | 4.098 | 0.655|
|                             | C3 Did GaoDe lower your sense of failure in the design process?           | 4.024 | 0.749|
|                             | C4 Did GaoDe assist you with enhancing your knowledge?                    | 4.317 | 0.642|
|                             | C5 Do you think you would remember the knowledge gained in the course better than the case you had only classes? | 4.024 | 0.811|
|                             | C6 Were you capable of making a balance between your knowledge acquisition and your knowledge application while playing the game? | 4.146 | 0.683|
| Satisfaction                | D1 What is your overall evaluation of satisfaction with GaoDe during the design process? | 4.049 | 0.764|
|                             | D2 Would you suggest GaoDe to your colleagues?                            | 4.634 | 0.482|
with more autonomy to accelerate their self-assessment procedure (Annansingh, 2019; Sanchez et al., 2017).

While paving the path for self-assessment, GaoDe mainly focuses on encouraging architecture students to create a suitable interactive environment, with no fear of being judged, allowing them to fill the gap between their knowledge in the design procedure. Accordingly, the respondents were asked whether GaoDe could make them interested in the design and maintain them motivated. The outcomes revealed a mean score of 4.073 and a standard deviation of 0.677, demonstrating that most users believed GaoDe was capable of increasing their motivation and helping them to continue their design activity through easy playing (C1). Furthermore, questions C2 and C3 with mean values of 4.098 and 4.024 and standard deviations of 0.655 and 0.749, respectively, made it clear that the majority of the users had pleasant experiences of interactive technology with an alleviated sense of failure through the design procedure using the GaoDe tool. The learners also reported greater knowledge of the studied topic after utilizing the tool. Concerning question C4, with a mean value of 4.317 and a standard deviation of 0.642, most of the respondents claimed that the GaoDe provided them with an opportunity to enhance their knowledge. Similarly, question C5, with corresponding values of 4.024 and 0.811, illustrated that the users believed that they were more capable of recalling the knowledge learned while playing the game compared to that gained through the traditional face-to-face method. In this regard, according to the answers given to question C6 (with a strong mean value of 4.146 and a standard deviation of 0.683), most of the learners thought that using the tool had assisted them to balance their knowledge acquisition and knowledge application, as a critical attribute towards the development of GaoDe. Nevertheless, the overall satisfaction with the game should also be investigated. The mean value of 4.049 and standard deviation of 0.764 proved that the learners mostly agreed that they had satisfaction with GaoDe through the design procedure (D1). The answers given to question D2 with a strong mean value of 4.634 and a standard deviation of 0.482 indicated that the users would highly suggest it to their peers.

As a result, teaching with technological tools and self-assessment seems can attract architecture students to learning, mainly because the HCI technology is associated with the nature of design (Savazzi et al., 2018; Xinogalos et al., 2017). As an interactive learning tool, the GaoDe can empower students in the design and self-assessment procedure with a grown level of innate motivation, self-awareness, and coherent knowledge (Rushton, 2005; Webb & Gibson, 2015). Accordingly, self-assessment became more visible and deeper, helping to identify and narrow the gap between their knowledge acquisition and knowledge application, and consequently, address various misconceptions they had previously had in a traditional education environment and lead them toward active elements in the learning procedure (Azriel et al., 2005; Davydova, 2018; Groenendijk et al., 2020; Oyelere et al., 2018; Palaigeorgiou & Papadopoulou, 2019). Hence, self-assessment directs the students in their activities by playing the role of a meta-cognitive tool (Martínez et al., 2020). While creating a mentality that inspires learners to experience new things, this tool eliminates the fear of failure and gives them the power to get involved in fun learning experiences (Javid, 2014; Lee & Hammer, 2011). Overall, these findings are
promising and seem to support those of the prior research, which revealed that serious games using HCI technology were appreciated by students, improved their motivation, and offer them higher self-confidence, in comparison with the face-to-face method (Alexiou & Schippers, 2018; Alfalah, 2018; Barrón-Estrada et al., 2021; Dib & Adamo-Villani, 2014; Ghanbarzadeh & Ghapanchi, 2021; Oyelere et al., 2018; Westera et al., 2020).

6 Conclusions

With respect to the advances in contemporary architecture and technology, new student-centered methods should be introduced in order to bridge the gap between the students’ knowledge acquisition and knowledge application in architectural education. Students should be active and contribute to their learning process, which should be motivating and interesting for them. On the other hand, games have always played a crucial role in the education of humans. By using serious open-ended games, a high motivation should be provided to pave the way for open and exploratory learning in the field of architectural education, which uses proven approaches to interact with a learner. Thus, using the educational method of student-centered and game-based learning, the current article has depicted a serious open-ended game as an educational tool to teach architectural design in a 3D CAD environment named GaoDe.

The GaoDe allows the students themselves to determine their design problems so that they can gain a better understanding of their learning process through self-assessment, rather than collecting information or memorizing facts in a passive process. This educational tool enjoys a natural multi-modal user interface for human-computer interaction (HCI) using the LMC and machine learning. The initial version of GaoDe is composed of different games of iconic buildings designed by famous architects. Students can take advantage of the multi-modal user interface for gesture and speech recognition while playing in a familiar CAD environment in an autonomous and real-time mode based on their knowledge and experience. Ultimately, they can observe their result in the form of a digital model, compare it with the design of the original architect, and perform self-assessment.

The questionnaire results revealed that GaoDe could aid the students in obtaining improved achievement from their learning activities compared to the face-to-face method. The integration of interactive technology and the self-assessment approach provides a wide variety of motivations and opportunities for engagement while enabling the learners to connect their activities and experiences with their learning and development in a meaningful way, filling the gap between their knowledge acquisition and knowledge application. Accordingly, it is obvious that the GaoDe framework provides an easy-to-use and robust tool, allowing the learners to comprehend the complexities of the architectural design procedure and self-assess themselves with no fear of being judged in architectural education using a 3D CAD environment. In addition, given its multi-modal natural user interface, the suggested tool results in a faster and deeper perception of the architectural design education and empowers the users with a limited experience for design in a 3D environment.
However, it is worth mentioning some constraints of the present study. First of all, a more long-term study is required to recognize the characteristics of game-based learning effective in the learning of architecture students through the design process, which can provide more information on the influence of self-assessment according to the use of interactive serious games. Secondly, due to the small number of respondents, this research may not be considered a well-established observation and would need a thorough experiment for implementation and instruction in the higher education system. Thirdly, GaoDe’s endorsement by teachers is critical for guiding the self-assessment process and motivating students to engage actively with GaoDe in order to avoid misunderstandings. To address these limitations, the authors have planned to perform a comprehensive and long-term retention investigation into the effectiveness of GaoDe with a large sample of teachers and students once the Covid-19 pandemic ends and students return to in-person classes. Moreover, a serious interactive game must be thoroughly developed to naturally stimulate student engagement using a combination of extrinsic and intrinsic motivators. Hence, further research is critical to enhancing the positive impacts of the GaoDe tool on student learning and engagement. In the next step, the GaoDe educational tool is expected to be developed to better understand for students given the Grasshopper’s capability of simulating various performances of a building, such as structure and energy.

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Data availability  Data transparency.

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Declarations

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