



APPLICATION OF ICT TOOLS IN ARCHITECTURAL EDUCATION: CURRENT TRENDS

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KUS: ICSTEM4IR-22/0053

Manuscript submitted: August 18, 2022

Accepted: September 26, 2022

Abstract

Information and Communication Technology (ICT), as the prime axis of educational development in the third millennium, influences how we live and our interactions with other people and their physical spaces. Rapid scientific and technical progress and the information revolution complemented by technology have given architectural education a new character and structure, leading to changes in the learning and teaching process. This paper presents a literature review on current ICT tools that can be successfully used in architectural education's learning and teaching process. This study identified a wide range of ICT tools currently being used worldwide in architectural education to help students learn more effectively and to guide teachers in approaching various teaching methods. This paper will focus on how ICT tools can support better architectural education, possible practical applications in site analysis, layout development, mapping crafting concepts and ideas, 3D modelling, and finally, presentation of students' work. After a comprehensive assessment of the various existing ICT tools and their practical applications, followed by critical reflections on the pros and cons of their use in architectural education, a new direction will be developed to guide the students and faculties of architecture in choosing the appropriate ICT tools when needed.

Keywords: ICT tools, architectural education, teaching methods

Introduction

Information and Communication Technology (ICT) is the prime axis of educational development in the Fourth Industrial Revolution (4IR) era. Societies are experiencing revolutions because of globalisation today. Changes in tools and their needs significantly impact culture and how people interact with one another. ICT is undeniably one of the most essential and influential tools affecting the world's interaction culture in the twenty-first century. It has revolutionized product design in the architecture, engineering, and construction (AEC) industries, as well as other fields where geometric calculation and visualisation are crucial (Cera et al., 2002). It also influences how we live and interact with other people and their physical space. The ways we communicate are evolving and adapting to new gadgets and apps, characterised by qualities such as mobility, interaction, and interconnection (Sánchez-Sepúlveda et al., 2018). Studies from different sources describe that

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DOI: <https://doi.org/10.53808/KUS.2022.ICSTEM4IR.0053-se>

the prospects of ICTs are the potential to create a new form of reality, where physical and digital environments are interwoven with the media and interconnections together throughout our lives (Masdéu, 2018; Reffat, 2007; Soliman et al., 2019).

Design is a multi-faceted, iterative, and complex human activity that is essential to many modern companies (Rahimian et al., 2008). Planners' and designers' modes of interaction are determined by the tools they employ (Donath et al., 2004). Interaction cultures in every design society are determined by the mediums utilised by the members of that communication and should be accessible to all members of the community (Rahimian et al., 2008). According to the experts, managing change efficiently and strategically appears to be the key to successfully implementing ICT into any educational system. The three stages of change that may be anticipated with the introduction of ICT are a gain in efficiency, an enhancement of current instructional techniques, and a complete transformation of the teaching and learning experience. (McCormick & Scrimshaw, 2001; Wang, 2009).

ICT has been found in studies worldwide to increase student learning and teaching approaches to help designers learn more successfully by giving teachers access to various fresh methods. It also strengthens the student-teacher bond and encourages interaction, creativity, active learning, and higher-order thinking among students. Masdéu (2018) identified three reasons that are responsible for limiting the use of ICT in architectural educational practice. First, current students have profound knowledge using ICT, as scholars termed them “digital natives¹” (Maksymiuk & Kimic, 2016). But unfortunately, in many cases, teachers are more focused on technical aspects and failed to provide them with the appropriate methodological tools and thought edifices that allow them to establish personal long-term learning methods in many circumstances. Secondly, Teachers and pupils only utilise ICT as a simple administrative tool. That limits the Internet's most appealing features: worldwide communication, unfettered reproduction, and group commitment. Finally, the in-efficiency of old-school teaching staff is not capable enough to teach their students to handle the technology and apply it in lifelong learning.

Various ICT tools are available, each with its own set of functions. Some ICT tools can only provide content for a specific subject, while others can be used to assess students' grasp of the topic (Deshmukh et al., 2019). It is crucial to determine what kind of innovations are in the market and whether students are interested in which types of tools. Thus, this paper aims to review new tools used in architectural education and help enhance teaching practice. Three objectives are chosen to achieve the aim; those are-

- To understand the effects of ICT tools in Architectural education.
- To identify the features and application of some most popular ICT tools.
- To prepare a matrix of evaluation parameters that will give direction to students and faculties of architecture for choosing the most appropriate ICT tools in the design process.

The matrix developed in this paper will help students choose appropriate ICT tools and uncover the newly emerging ICT tools and their application through a detailed study of their features.

Impact of ICT on Architectural Education

The use of digital technology in the design studio curriculum in architecture school has increased in the twenty-first century. ICT in education is widely acknowledged as a necessary component for future social and economic development and as a potential base for enhancing access to education through online and distance learning (Richards, 2004). These computer-assisted drafting, enumeration, modelling, and analytic technologies became critical pedagogical nodes in the design studio and altered the broader curricular structure of architectural education (Soliman et al., 2019). This section describes the various trends developed for adopting ICT in architectural education and practice. According to Andy, technology impacts architectural education

¹digital natives – technology driven young generation, who feel safe only in environments dominated by electronics.

and training on two distinct planes-skill levels and at the level of work process and professional culture. During the 1970s to 1990s, ICTs transformed the manual skills of architects employed in drawings, written reports, specifications, and documentation. The next significant change came with the introduction of internet service, which is continuing. Substantial differences were observed, and benefits materialised through adopting automation in the work process and started working in a collaborative environment. This paper has grouped the significant changes into five major categories. It highlights the opportunities and challenges faced by designer communities, how they are addressed, and the various discourse patterns that have emerged in the architectural academic community. Figure 1 shows the significant impact of ICT on Architectural Education during the different time frames.

Traditional methods

Since the Bauhaus teaching experimentation in Germany in the 1930s, the traditional studio has grown in popularity in architectural education (Gül et al., 2012). It has dominated architecture education for decades in a number of nations, displaying numerous advantages such cultivating critical, inventive, and practical thinking (Ibrahim et al., 2012). Traditional methods of architectural education tools are mainly based on freehand sketching, the mechanical drawing of 2D and 3D sketches (Soliman et al., 2019). The end of the inclusion of ICT into the Traditional Design Studio model introduced significant changes in the method architecture is taught, the location where learning takes place, and the number of times students are trained (Masdeu, 2018). In recent times, entire digital teaching through the integration of different ICT tools has become the main subject of teachers, researchers, and students.

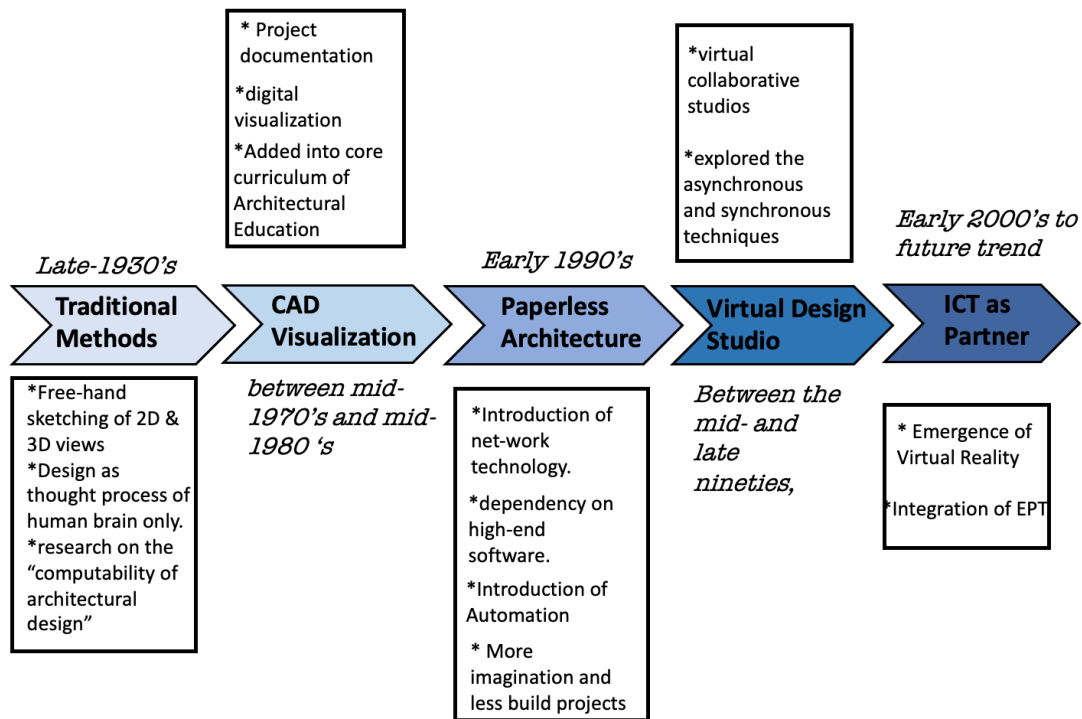


Figure 1. Impact of ICT on architectural education through time.

Since the early 1960s, a lot of work has gone into describing and explaining the design process and the creation of design solutions (Moum, 2005). Sketches were an essential element of the traditional design process, as they help to fixation idea formulation and testing, reducing concept vagueness and ambiguity. Many academics believe that the graphic form of a sketch or drawing can help speed up the formation of valuable ideas and notions (Fish & Scrivener, 1990).

The communication function of drawings is crucial in everyday design practice since debate and feedback have a significant impact on the design process. In order to reduce concept vagueness and ambiguity, sketching as an external fixation of ideas requires early development and testing of these concepts. Many scholars think that a sketch or drawing's visual style might hasten the development of important ideas and concepts (Fish & Scrivener, 1990). So, we can claim that using drawings is unquestionably a crucial component of the natural design process, but design academics are just now beginning to examine and analyze it in greater detail to determine just how important it is.

CAD visualisation

During mid-1970 and mid-1980, CAD became an essential tool for project visualisation and documentation for architectural education. Instead of design features and analytical abilities, the CAD (Computer-Aided Design) technologies used in the design process enable drafting and modeling. The work of drafting or modeling has not altered (Kalay, 2004). The introduction of CAD systems and developed product visualisation help students learn various stages of the design process and gain a deeper grasp of how an object works before it is built in real life. Students may see how their three-dimensional objects will fit into the right real-world environment (Iyendo & Halil, 2015). However, Henri (2003) cautioned, that conventional design tools like manual sketching, which frequently offers the essential direct physical interaction between the hand and the brain, could be replaced by digital tools. Again, digital tools have replaced physical architectural models with a collection of enticing graphics that are usually geared to wow, providing an attractive, easy, and economical alternative.

Paperless architecture

Led by the School of Architecture at Columbia studios, the early 1990s were distinguished by eliminating as many hand-drawn designs as feasible and the development of a substantial reliance on high-end software. Such movement is known as Paperless Architecture. The software's capacity to generate unusual effects was eventually applied to building circulation, mobility, and program change studies. Such a program quickly proved to be more than just a rendering tool; it began to inform and transform the design process. Much criticism was raised, and the projects were eye candy and endless loops of aesthetic reproduction rather than pushing architectural theory and practice towards a new direction (Andia, 2002). According to Guney (2015), the problem with employing computer apps is that it causes pupils to become addicted to them and design projects without creativity. Students began using computer application tools as early as the conceptual stage of their exploration of specific legal issues (Henri, 2003). Many educators and practitioners, however, have advocated for combining physical and digital design processes rather than using one method alone (Soliman et al., 2019).

Virtual design studio

As globalisation and increasingly complicated techniques and goods necessitate more excellent teamwork, the importance of collaboration is expanding, and the intricacy of the challenge becomes overwhelming for one person. The focus shifts from the individual to the collaborative design process, introducing a new dimension to the idea generation process: individual-group interaction (Lawson, 1997). Through the exploration of asynchronous and synchronous techniques in remote design collaboration, the concept of Virtual Design Studios (VDS) emerged between the mid and late nineties (Andia, 2002). By utilizing tools like video conferencing, Internet publishing, e-mail, Web3D, and digital modeling, students gain a greater understanding

of new modalities of collaboration and media integration in design methods (Reffat, 2007). VDS generally encourages creativity and makes it easier for pupils to communicate, express, and develop their imagination (Schnabel, 2011). Additionally, the VDS enhances the architectural experience by introducing studios to many design cultures and a wider range of design criticism. (Reffat, 2007). Stepping away from traditional linear and unidirectional teaching methods can enrich architecture education by encouraging independence, efficient time management, spatial flexibility, and other impossible social connections in conventional classroom settings (Rodriguez et al., 2018).

Reffat (2007) demonstrated the drawbacks of the VDS approach by applying it to first-year architecture students at the University of Sydney in Australia. These limitations include firewalls' bandwidth capacity and the amount of data that can be transferred in (near-) real-time in a multi-user online environment. The author also advised considering Modelling objects and their geometries while adopting Virtual Environments (basically Active worlds) in virtual architectural design studios. However, such technical constrain are expected to be overcome shortly.

Future trend: ICT as partner

ICT is anticipated to soon play a more significant role than only serving as a medium; it may even take on the function of a dependable partner in the design process. When ICT advances and auxiliary tools effectively serve as knowledge integration tools, decision support tools, and design assistant tools, ICT will be employed as a partner (Sariyildiz & Van der Veer, 1998). It is thus necessary to create new procedures and strategies to realize the objective that computers may be included into the educational process and serve as a trustworthy partner in architectural education. When it comes to implementing and giving innovative instructions, the demand for such approaches and procedures offers difficult difficulties to architectural educators with competence in information and communication technology. An approach has been developed that anticipates the new generations of supportive, collaborative architectural design and studio teaching, where architects are designing with intelligent agents based on the viewpoint of situated digital architectural design (Reffat, 2006).

Two technological trends will guide the future of digital architecture. The first is creating mixed reality: environments that create more intelligent and interactive spaces. Secondly, the use and functions of traditional buildings are expected to alter due to the emergence of fluid, universally accessible, high-bandwidth networks (Andia, 2002). The development of virtual reality (VR), based on geometrical and graphical representation allows users to walk through a 3D area and view items and their relationships to one another. Such possibility of a realistic imitation of a real-world environment, combined with the experience of spatial dimension, has the potential of becoming a powerful tool for this time. Masdéu (2018) assumes that the future should be heading towards integrating EPT (Empowerment and Participation Technology) in learning. EPT will be utilised to influence and generate trends (on a social and professional level), translate data into collective knowledge, and manage, create, and communicate information. In other words, participation and open architecture will become essential to a virtuous circle of contribution and collaboration that will help typical knowledge flourish.

Some architectural schools also implementing the method of blended learning in the Design studio to combine the flexibility and efficiency of digital techniques of learning with communication strength of face to face learning (Achten et al., 2011). Using the blended approach (combination of on-site activities with online tasks) Masdéu and Fuses (2017) proposed iLab project as a part of their PhD research. The goal of such project was to develop research projects linked with various field of architecture, collaboration with experts of different fields, and companies from the sectors of architecture, engineering, and construction. Further, to generate student's self-learning capacity Hanna (2018) explored the application of Augmented Reality (AR) on mobile devices on a large scale. Mobile Augment Reality (MAR) allows to design and create an innovative learning scenario in real learning environment at low cost, where students can use their own mobile as

application tool. Despite the prominent role of MAR technology in architectural education author also indicate the difficulties and challenges facing the application in local reality.

Architectural curricula tend to prioritize the field of construction, narrowing the possibilities to renew skills with spatial ICT. Santos et al. (2021) recommended a better integration of GIS in architectural design, heritage, and urban and regional planning courses to identify and visualize previously invisible evidence, synthesis and map temporal information and combine data from various sources to generate new data and hypotheses. A paradigm shift, referred as Next Architecture is being signaled by the growing usage of microservices, cloud, containers, and orchestration. Basic principle of Next Architecture's is that software architecture should be flexible, agile, robust, and change tolerant. Cloud computing, container virtualization and orchestration, microservices, serverless computing, and functions-as-a-service (FaaS) computing are the main elements and methods that make up Next Architecture. Decomposition, the principle that unites the Next Architecture, is also broadly known, often used, and (most of the time) without controversy. The two main objectives of architecture are to build software architecture that is more adaptable and robust, as well as to improve the entire service experience for clients. Next Architecture is not coupled to any specific architectural regime for this second goal (Magoulas, 2019).

Materials and Methods

A secondary literature search was conducted in this study. Secondary literature consists of interpretations and evaluations derived from the primary literature. It reviews, collects, criticises, integrates, and summarises literature to address topics and draw conclusions (Cronin et al., 2008). This study is also based on secondary data. Secondary data consists of existing datasets, reports, and documents, usually edited by others or organisations, and often used for purposes other than current analysis. Secondary data from national and international peer-reviewed journals, the Internet, books, etc., were collected for this study. However, this paper focuses on investigating the most preferred ICT tools and their capabilities, not all available ICT tools.

Most Popular ICT Tools

As mentioned earlier in the method section, this section and the following section illustrate the most popular ICT tools and their key features.

Microsoft office

The Microsoft Office package is necessary for architecture students in their first year and upwards. Students employ the same resources and methods as experts. Microsoft Office is a very versatile application. Its built-in features allow it to be the foundation of so many projects. Microsoft Office can also create floor plans for room organisation, seating arrangements, and more (Microsoft, 2022).

Auto CAD

AutoCAD was created in 1982 with the goal of bringing the field of computer-aided design (CAD) from mainframes to desktop computers. The most popular CAD application in the world by 1986 was AutoCAD. For the most part, architects use AutoCAD as a 2D drafting program to create floor plans, elevations, and sections. With preconfigured items like walls, doors, and windows that act like real-world things, the program expedites the drafting process. To help with drawing and design work, AutoCAD offers specialized toolkits for architecture, mechanical, electrical, and other fields (Autodesk Inc., 2022b).

3D Studio Max

A 3D computer graphics tool called 3D Studio Max was introduced by Autodesk in 1996 and is used to produce 3D animations, models, games, and photographs. It is commonly utilized by television production companies, video game makers, and architects in addition to them. With realistic renderings, expert lessons, and animations, it enables users to generate comprehensive architectural visualizations of their projects. Users

will be able to quickly convert 2D drawings into 3D objects that can be textured, generated, and lighted using 3D Studio Max. Users of any CAD skill level may produce accurate 3D architecture models. Additionally, being a member of the Autodesk family, 3D Studio Max can effortlessly import files from Revit and AutoCAD (Autodesk Inc., 2022a).

Corel Draw

The Corel Corporation created and sells the vector graphics editor known as Corel Draw. The bitmap image editor Corel Photo-Paint and other graphics applications are part of the Corel graphics suite, which goes by the same name. The most recent version, which is marketed as the CorelDraw Graphics Suite, was made available for Windows and macOS in March 2022. It is made for modifying 2D graphics like posters and logos. It automates design chores, produces beautiful architectural drawings, paperwork, and schedules, and improves materials to aid in the purchasing and selling process.(Corel Corporation, 2022).

SketchUp

As a versatile, simple-to-use, and entertaining tool for creating 3D material, SketchUp was created in 2000. It is appropriate for applications in landscape architecture, interior design, mechanical engineering, and architectural drawing. Despite having far less functionality than any other platform we have evaluated, SketchUp is one of the easiest architectural software programs to use and comprehend. Before advancing to more sophisticated tools, it is a great approach for students to become comfortable with 3D modeling. (Trimble Inc., 2022) .

Lumion

A 3D rendering program made specifically for architects is called Lumion. With the aid of the architectural rendering program Lumion, it is simple to illustrate how ideas will transform into feelings and sensations that people will really have. Lumion's quick, easy, and dependable integration into any design workflow makes rendering experiences more fulfilling and entertaining. Lumion's goal is broad compatibility to guarantee that every architect and designer may access architectural visualisations easily and rapidly, independent of CAD software or 3D modeling (Act-3D, 2022).

Archi CAD

Archi CAD was the first CAD program that could produce both 2D and 3D geometry on a personal computer as well as building information modeling (BIM) products for personal computers. It was created in 1982 and published in 1987. Compared to AutoCAD, it is not as popular. However, Archi CAD lets users to make models utilizing built elements, such as walls, windows, beams, and features, in contrast to AutoCAD, which generates drawings from 2D lines. Additionally, Archi CAD incorporates the BIM approach, enabling collaboration between architects, engineers, and contractors on the same project (Graphisoft, 2022).

Rhino (aka Rhino3D)

Instead of the conventional mesh-based application used in most 3D applications, NURBS (nonuniform logical backbone based) mathematical modeling was utilized to build Rhino, a 3D graphics and CAD program, in 1998. Rhino can provide free-form curve and surface representations that are exact in mathematics. Rhino's advantage as a software program for architectural design is its capacity to simulate intricate intersections of curving roofs or naturally asymmetrical buildings. Additionally, it makes it simple to import drawings and models so users can start modeling right away without having to spend time learning CAD. Additionally, Rhino offers a sizable database of plugins and visualization tools for automating any project's intricate modeling and detailing procedures. Rhino designs may be sent to 3D printers and other production processes to produce actual products. (McNeel & Associates, 2022).

Revit

In order to enable BIM workflows and aid architects, designers, and engineers in planning and tracking all phases of planning and building, from idea to completion, Revit was developed beginning in 1997. Version 1.0 was launched in 2000. Since being bought by Autodesk in 2002, this technology has been integrated with AutoCAD and other firm goods. Using a centralized database and template, managing team members from various disciplines on a project is simple. Revit lets users create models using objects like walls, roofs, beams, windows, and doors rather than just straight lines. A model's modifications are instantly reflected in all views, including plans and elevations. Users of Revit Automation may also build a library of easily accessible items for use in any design or project. The capacity to share work is Revit's greatest strength. Throughout the course of a project, several users can access the same model that is housed on a local network or in the cloud using BIM360. This makes it simple for architects to work together with teams working on electrical, mechanical, and structural design using the same tools (Autodesk Inc., 2022d).

Grasshopper 3D

Grasshopper 3D allows architects to use parametric design to improve the efficiency of their workflow. Grasshopper has several tools that help automate routine tasks. Most design software must copy and paste the essentials, such as lines, to reuse them. Some software uses matrices to reduce the time required for these tasks. Grasshopper's use of variables simplifies such actions. It only needs to simply enter a number into a variable to generate the desired number of elements. Grasshopper also benefits from being open-source software. It has a community around it that is constantly developing new plugins. Along with this, Grasshopper is closely related to Rhino 3D. This integration eliminates the need to understand coding using Rhino 3D (Davidson, 2022).

Maya

There is disagreement about the usefulness of Maya in architecture. Some people think it's too generic design software. They note that it lacks many tools that more specialised software loves. However, the absence of these constraints is often helpful to designers. Maya is the perfect choice for exploring concepts beyond what other types of software allow. It gives more freedom in work. This drives innovation in design. Many people use Maya to develop new ideas before transferring their Maya models to other software. This freedom allowed Maya to be accepted in the field of architecture. Many 3D modelling beginners also use Maya as an educational tool. It will enable them to familiarise themselves with the basics of 3D modelling without having to deal with the constraints of specialised software. Its tutorials prove very useful. Furthermore, Maya has a great community around it. This makes it easier for designers to get help if they get stuck at work (Autodesk Inc., 2022c).

Adobe Photoshop

In order to develop architectural renderings, visualizations, and diagrams for customer presentations and papers, Adobe Photoshop is widely used. Photoshop may be used for a wide range of jobs in architecture, and in many fields, architecture is the main tool for producing and altering pictures. Photoshop may be utilized by both novice and professional users, and many users start using it during their initial training. Photoshop frequently resembles the standard assortment of CAD and 3D architectural packages in terms of software and digital tools used by architects every day. For architectural photographers, who employ tools to modify, edit, and improve photos, this is different (Adobe, 2022b).

Adobe Illustrator

Using Adobe Illustrator, architects, engineers, and construction specialists may produce impressive digital presentations of their work that can be combined with CAD and other Photoshop artwork. These might be helpful for outlining a project's vision as part of a proposal or during the building process. Many of the finest

architectural, engineering, and construction firms in the country use Illustrator's features to transform thoughts and ideas into drawings while developing their projects (Adobe, 2022a).

Blender

Blender is a free program tool to help create unique designs. Blender also provides handy tools for architecture. Besides high-resolution modelling, it offers robust texturing, animation, rendering, and other 3D development tools. Blender's collection of tools and addons makes the workflow effortless like other programs. Blender and CAD software are combined by certain architects and designers. Concept studies should be conducted using Blender first, followed by CAD software, Blender for graphics, and CAD software for documentation (Suite, 2022).

ArchGIS

All forms of data may be created, managed, analyzed, and mapped using a geographic information system (GIS). GIS ties information to a map and combines locational data with several forms of descriptive data. In science, architecture, and practically every other field, this offers a framework for mapping and analysis. GIS aids architects in comprehending trends, connections, and spatial context. The advantages include better management and decision-making, as well as enhanced communication and efficiency. GIS offers a wide range of possible applications in architectural study and practice, particularly in the fields of community planning, urban design, and site selection. The digital depiction of actual things is one of the key areas where GIS and architecture interact (ArchGis, 2022).

Results

After studying the above ICT tools in detail and considering the different characteristics of each of these ICT tools, a matrix (Table 1) has been developed to guide academics and professionals in selecting the appropriate ICT tool for their needs. Table 1 shows the significant features of fourteen selected ICT tools primarily used in architectural education. The characteristics that were considered while designing the matrix can be summarised as follows:

- Operating system: suggests the type of operating system, e.g., Windows, macOS, iOS, Android, required and supported by the tool.
- License: categorises different licensing options.
- Trial versions: recommends whether the tool provides any trial version.
- Free version for students and educators recommends whether the tool provides any free version for students and educators or not.
- Support cloud storage: guides whether the tool facilitates online or offline storage.
- Editing, illustrating, and annotating 2D graphics recommends whether or not the tool provides editing, illustrating, and annotating 2D graphics features.
- 2D architectural drawing and drafting recommends whether the particular tool provides 2D architectural drawing and drafting features or not.
- 3D modelling and visualisation recommend whether or not the tool provides 3D modelling and visualisation features.
- Support animation: whether the tool features an animation facility or not.
- Collaboration: whether the tool supports collaborative work for team members in different geographical locations.
- Mobile app: indicates whether the tool supports the mobile platform.

- Upgrade regularly: suggests whether the tool's regular update feature is available.

Table 1. Features of the most popular ICT tools of architectural education

Features of ICT tools	Name of ICT tools														
	Microsoft Office	Auto CAD	3D Studio Max	Corel Draw	SketchUp	Lumion	Archi CAD	Rhino 3D(aka Rhino3D)	Revit	Grasshopper 3D	Maya	Adobe Photoshop	Adobe Illustrator	Blender	GIS
Operating system	Windows, macOS, iOS, Android	Windows, macOS, iOS, Android	Windows 7 or later	Windows, macOS	Windows, macOS, iOS, Android	Windows 10 or later	Windows, macOS	Windows, macOS	64-bit Windows	Mac, Windows, iOS, Android	RHEL/CentOS 7.3, Windows 7, macOS 10.13 and later on	Windows macOS, iPadOS	Windows 10 and macOS	Linux, macOS, Windows,	Windows, macOS
License	Proprietary	Subscription	Subscription	Proprietary	Subscription	Subscription	Proprietary	Proprietary	Proprietary	Proprietary	Trialware	Proprietary	Proprietary	GPL	Subscription
Trail versions	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N/A	Y
Free version for students and educators		Y	Y	N	Y	Y	Y	N	Y	Y	Y	N	N	Y	Y
Support Cloud storage	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y
Editing, illustrating, and annotating 2D graphics	Y	N	N	Y	N	N	Y	N	N	N	N	Y	Y	N	Y
2D Architectural Drawing and drafting	N	Y	N	Y	N	N	Y	Y	Y	N	N	N	N	N	Y
3D modelling and visualisation	N	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Support Animation	N	N	Y	N	Y	Y	Y	Y	Y	Y	Y	N	N	Y	Y
Collaboration	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
As Mobile app	Y	Y	N	N	N	N	N	N	N	Y	N	Y	Y	N	Y
Upgrade regularly	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y

Discussion

Table 1 demonstrates that the windows system can operate all the tools, but some needed an upper version; for instant, 3D Studio Max required windows 7 and later, whereas Lumion required windows 10. macOS can also operate most, but few cannot. For example, 3D Studio Max, Lumion, and Revit cannot be used by macOS. All the ICT tools selected for this research have provided their trial version varying from fifteen days to three months, but some offer a free version for students and educators. All the software of Autodesk has a free version for a certain duration, but Adobe Photoshop, Adobe Illustrator, Microsoft Office, and Rhino do not provide a free version for students and educators. All the ICT tools support cloud storage to store data on the Internet except Archi CAD, but collaboration is possible for all those tools. Microsoft Office, Corel Draw, Adobe Photoshop, and Adobe Illustrator are usually used for editing, illustrating, and annotating 2D graphics. In contrast, Auto CAD, Archi CAD, and Revit are popular for 2D architectural drawing and drafting and sometimes for 3D modelling and visualisation. However, 3D Studio Max, SketchUp, Lumion, GIS, Rhino (aka Rhino3D), Grasshopper 3D, Maya, and Blender are more accepted tools for 3D modelling, visualisation, and animation. Though all the software except Grasshopper 3D is upgraded regularly, all the devices are not available as mobile apps.

Conclusion

Fourteen most popular ICT tools for architectural education were identified. Microsoft Office, Auto CAD, 3D Studio Max, Corel Draw, SketchUp, Lumion, Archi CAD, Rhino (aka Rhino3D), Revit, Grasshopper 3D, Maya, Adobe Photoshop, Adobe Illustrator, and Blender. The features taken into consideration to study those most popular ICT tools are operating system, license, trial versions, free versions for students and educators,

support cloud storage, editing, illustrating, and annotating 2D graphics, 2D architectural drawing and drafting, 3D modelling and visualisation, support animation, collaboration, mobile app, and upgrade regularly. Based on those most popular ICT tools and critical features, a matrix was developed to guide academics and professionals in selecting the appropriate ICT tool for their needs.

We are entering a new era of ICT applications for architects and architectural education, just as the architectural profession is evolving under the impact of ICT technology, and the current visualisation tools are reaching their limits. The educational institutions that provide architectural training must adjust to these ICT advancements.

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