Implementation of integrated BIM-VR into construction management curriculum: lessons learned and development of a decision support system

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Abstract. Several educational institutions and universities have introduced Building Information Modelling (BIM) and Virtual Reality (VR) courses separately in the construction management (CM) programs around the globe, and others are in the process of integrating them into their curricula. However, fewer institutions have included integrated BIM and VR into their courses. The industry needs for integrated BIM-VR are not fully recognised by universities due to the lack of a guideline and cognitive dissonance between academia and industry. As a result, most universities do not have a rigorous strategy for developing BIM-VR teaching topics and plans. This study firstly aims to report on some of the employed processes by university lecturers and academics in an Australian University to integrate BIM-VR education into CM curriculum. The review on the secondary sources indicates that the integration of BIM/VR education requires the consideration of three aspects including: industry needs, course contents, classroom size and software and hardware selection. The second aim of this paper is to develop a decision support system by utilising the PROMETHEE method as one of the multi-criteria decision-making approaches. The findings of the secondary sources and development of the decision support system help the educational institutions and practitioners for their future BIM-VR implementation initiatives.

1. Introduction

The complexity of construction projects which require tighter collaboration and an enhanced understanding about the processes [1] call for further interactive tools and methods of teaching [2]. In addition, some of the students had no prior construction background nor in-situ experience. Hence, to improve the students' abilities to understand the construction process sequences and technical details both BIM and VR have been considered effective.

However, fewer educational institutions have included integrated BIM and VR into their courses. A VR-BIM system enables users to interact with digital objects by simulating physical presence in virtual spaces [3]. In addition, using BIM-based VR provides the ability to reflect any real-time changes in the model [4]. Several universities around the world are incorporating BIM and VR separately into their curriculum. However, less attention has been given on how these two approaches have been integrated into the construction management curriculum concurrently [2]. In this paper, we share our methodology in implementing BIM-VR into the construction management curriculum in one of the Australian universities and develop a decision support system to help the educational institutions and practitioners on how to implement them in their own context.

2. Literature Review

2.1. Building Information Modelling (BIM)

Over the last few years, BIM has gained increasing attention as a new method for executing and managing construction projects. The central idea of BIM is to provide information on a shared database so that stakeholders can develop a virtual building information model collaboratively [5]. It is worth to note that BIM is more than just a technology providing unparalleled visualisation and intelligent models that enhance business capabilities in the Architecture, Engineering and Construction (AEC) industry [6]. With BIM, team members can upload, extract, update, or modify information in a common digital representation. Through this process, project members can reuse building information throughout the life cycle of a building. BIM has infinitesimal dimensions (nD) and has been used in the industry for many different applications such as three-dimensional (3D) visualisation and scheduling (also referred as 4D as adding the time or process dimension to 3D models), quantity take off, safety, clash detection, maintenance and facility management [7].

With the increasing needs of BIM-related software in the Architectural, Engineering and Construction (AEC) industry, one of the growing concerns among both academic institution and researchers is how to effectively incorporate them into the construction management curriculum to improve the students' knowledge and skills in the context of BIM projects. There is a consensus that BIM education should cover all aspects of BIM, including human factors, processes factors, and technological aspects. In addition, according to [8] there are different approaches to incorporating BIM into the construction management curricula including the followings:

- Stand-alone course: This is addressed by introducing a new BIM course. Students usually take a lower-level course where they learn the basics of BIM and how to create a 3D model of a building.
- Another way to teach BIM is to use it in a capstone project. In this approach, even though students learn BIM throughout the project cycle, the limited duration of the course limits the learning process.
- Embedding BIM in existing courses
- Combination of both a stand-alone course and integration into existing courses

We have adopted a *stage-based* approach starting from incorporating a new BIM course and gradually move towards incorporating it into various courses throughout the program. However, during the COVID-19 pandemic, lecturers of construction management courses faced several challenges when teaching BIM-related software. The facilitators of the course responded to the issues by providing pre-recorded videos explaining precisely how students should create a five-story building model using BIM-authoring software. [9] points out the difficulty of learning and following live online BIM courses. We discuss how the inherent complexity of BIM software and tools makes its remote learning challenging. [10] re-emphasised the importance of developing a learning environment that allows students to "browse content after class at their own pace" so they can repeat the lecturer's instructions. Students in construction management participated in weekly virtual question & answer sessions during which they could share their screens for support in their modelling exercises. Additionally, the live lectures included a set of visual content and videos to demonstrate how BIM-related tools and software are used. Nevertheless, due to the inherent complexities the application of integrated BIM-VR remained a challenge during the pandemic since students could not get access to the VR headsets.

Undergraduate Construction Management courses moving into BIM-VR implementation:

- BUIL1256 Construction Planning and Design (3rd year)
- BUIL1264 Construction Specialisation (final year)

This paper will present the experience of one of the above courses to demonstrate the process and learning experience. Many universities and AEC-related educational institutions in Australia have adopted Revit and Navisworks for 3D and 4D BIM applications. Although not exhaustive, the following table presents some of the technical details of adopted software in this study (Table 1).

Table 1. Key technical details of software BIM applications.

BIM software	3D BIM (with building geometry)	4D BIM (with process timeline)
Scope and main capability	Revit 2022 3D BIM - modelling	Navisworks 4D BIM - scheduling and creating federated model
Price	$450 monthly subscription (One-year free Autodesk license for students)	$170 monthly subscription (One-year free Autodesk license for students)
System requirements (Entry level configuration)	8 GB RAM 30 GB free disk space	2 GB RAM 15 GB free disk space
Alternative BIM software applications	Archicad, Rhino, 3DsMax Bentley, Formit, SketchUp Pro, Dassault Systems Catia	Revizto, Twin Motion, Infraworks, Inventor, Dassault Control Build, Primavera, Synchro Pro

The above table is not intended to be an exhaustive review but rather as comparison during the selection criteria for this paper. The combined authors of this paper have continued utilising open source and proprietary BIM applications and documentation standards.

2.2. Virtual Reality (VR)

Virtual reality's visual representation allows for integration of higher degree of freedom (DoFs) than traditional education and training approaches, such as static images and two-dimensional (2D) drawings [11]. The goal of immersive VR is to provide users with an immersive experience by using special hardware, such as the head-mounted display and sensor gloves to create an immersive environment. Using a VR headset, students can view project designs and site plans using their mobile devices or desktop computers. It empowers them to use their ingenuity to identify potential issues and resolve them in a simulated environment. As the user moves around in the virtual environment, their position also changes.

This is even more crucial due to pandemic-related concerns about safety, since the AEC companies are looking for new forms of collaboration by using virtual reality that don't require everyone to be in the same room. A review of VR and its uptake is beyond the scope of this paper. A summary table is provided here below with applications of VR within AEC domain.

Table 2. Key applications of BIM-VR for the construction management curricula.

Functions	Author and Year	References
Architecture and Design Visualisation (3D VR)	Bassanino et al. (2010); Wang et al. (2018); Abdelhameed (2013); Dunston et al. (2011); Liu et al. (2020); Pratama & Dossick (2019), Aranda-Mena (2021)	4, 11, 17, 18, 19, 20
Defect identification and constructability analysis	Arashpour & Aranda-Mena (2017); Asgari & Rahimian (2017); Ahmed (2018); Boton (2018); Wang et al. (2018)	2, 10, 11, 22, 23
Facility management and maintenance	Shi et al. (2020); Shamsuzzoha et al. (2021); Barkokebas et al. (2019); Ji et al. (2018)	24, 25, 26, 27
Material management	Zhang et al. (2019); Hsu et al. (2019)	29, 30
Scheduling (4D VR progress tracking)	Zhang & Pan (2021); Getuli et al. (2020); Ahmed (2018)	23, 30, 31

Safety and construction training	Sidani et al., (2021); Sacks et al. (2013); Zhao & Lucas (2015); Le et al. (2015); Li et al. (2018); Jeelani et al. (2020); Pedro et al. (2016); Wang et al. (2018)	11, 14, 23, 33, 34, 35, 36, 37

Although the focus of this paper is on construction management (CM) students, the authors have been working on VR applications in architecture, design, safety, and sustainability. Key value for CM students is the ability to walk through BIM models prepared by them or third party to visualise the different design and construction scenarios; compare them; and learn how to decide on the best design, material, and process for the projects. Practical decisions must be discussed during course guideline such as hardware capabilities and limitations, class size and the intended functions [12]. In a study conducted by [13], the cost of the hardware and difficulty of implementing even a basic VR application made teaching VR problematic. One of the main tasks in incorporating VR into the education context is to choose among the different Head-Mounted Display (HMD) headsets. There are several VR applications in the market which makes it sometimes a challenging decision-making issue. For this study and based on a secondary investigation, the most common VR applications are identified as Oculus Rift, Gear VR and HTC Vive. Table 3 shows the technical details of these three VR applications.

Table 3. Technical details of hardware VR applications

VR Apps / Technical specs.	Oculus Rift	Gear VR	HTC Vive
System requirements (I)	At least 8GB of RAM	At least 4GB of RAM	At least 4GB of RAM
System requirements (II)	At least two USB 3.0 ports along with an open HDMI port	USB type-C & Micro USB	At least one USB 2.0 port in addition to an open HDMI port
360º head movement	Yes	No	Yes
Field of view	110 degrees	96 degrees	110 degrees
Set up	Almost easy	Very easy	Almost easy
Power usage	4.5 Watts of power	1.5 V. (2xAAA)	3.5 Watts of power
Price	$399 AuDll	$99 AuDll	$599 AuDll

3. Technical lesson on integrating BIM-VR for construction management education

The final stage is to bring both, BIM and VR into a classroom or computer laboratory environment. Some of the main firsthand experience lessons the context of construction management education are as follow:

- Creating a BIM model (3D representation of a building) by using design-authoring software such as Revit between BIM authoring tools and game engines offering VR capability.
- Integrating VR and BIM through game engines to ensure compatibility between BIM authoring tools and VR applications as well as improving visualisation and overcoming incompatibility (e.g., Tridify for Unity, Datasmith for Unreal Engine and SimLab Composer for dynamic visualisation).
- Improved visualisation and optimisation and visual enhancement of models by using software such as 3Ds Max, or Rhino reducing file size and solving interoperability issues for datafile exchange.
- Establishing a database to render non-geometric information from a BIM model to a VR setting.
- Providing hardware - In the case of hardware, Head Mounted Displays (HMDs) such as the Oculus Rift can be used. In a virtual environment, HMDs can track motion and rotation and provide a realistic experience, for example by simulating lighting.

For more on integrating BIM-VR refer to [4] for Twin Motion by Epic Unreal BIM-VR live streaming and real-time rendering and broadcasting attributes and [14] for Unity engine.

4. Educational lessons from Construction Specialisation subject

An internal course survey was conducted to final core capstone and work integrated learning Construction Management subject. The Construction Specialisation subject is also offered as an elective to Civil Engineer students. The central theme of the subject is on transport infrastructure provision including construction, planning, design, finance, and lifecycle operations. The context of this subject is the current Melbourne Metro and Airport Rail Express projects. A component of BIM concept modelling for a rail or metro station takes place during tutorials. Two assessment stages have been conducted with BIM. Individual submission and BIM integration into an Expression of Interest Report prepared as a team (n.6). The EOI is submitted as a Public-Private Partnership where students need to think of the proposals as an integrated project delivery including finance.

The individual exercise requested student to mass-model a metro or railway as to examine and extract the following information from the model:

- Gross floor area, lettable floor area and public and social amenity space.
- Planning and construction staging with key milestones.
- Solar gain analysis for building integrated photovoltaic (BIPV) installation integrated with operational cost.

Enrolments for the 2021 offering reached n.380 and 367 responses were received in relation to BIM learning. 72% (n.261) core students and 27.5% (n.99) elective students, a summary is here provided:

The BIM authoring software was Autodesk Revit and Formit. Optional tools included Archicad and SketchUp Pro. BIM analyses software applications included CosteX™, Navisworks, Revizto™ for cost and staging modelling and Insight for energy calculations and BIPV photovoltaic design. Video tutorials were pre-recorded for each tool and exercise. This gave the opportunity to record as many short videos as needed for class needs and requirements. Weekly follow-ups were conducted as part of tutorial sessions, three focused BIM tutorials were distributed within the semester and an ongoing BIM blog/discussion board for the 12 weeks of semester.

The Virtual Reality (VR) component was only as optional due lock-down and unavailability of hardware including headsets. Still, students were encouraged to upload their BIM models onto Autodesk BIM Viewer. This was not an assessed component and still got an overwhelming class response of 92.9% (n.338) uploading and publicly sharing their models on the cloud (for one month) whereas only 8% (n.29) decided not to share their models. A second more complete/elaborated VR option was to upload the model onto TwinMotion™ VR (Epic Games Engine). This was mainly explored with postgraduate Sustainability and Design students and reported in [4].

4.1. Survey results:

Profession/Discipline:

- Construction Management 63.2% (n.230)
- Civil Engineering 31.9% (n.116)
- Project Management 2.5% (n.9)
- Quantity Surveying 1.9% (n.7)
- Architecture and Design 0.5% (n.2)

Do you think you will continue using 3D modelling in your future career? Yes, 64.1% (n.234), Maybe, 30.4% (n.111) and no 5.5% (n.20). If yes, what else would you like to learn/keep learning?

- Revit 37.6% (n.126),
- Formit 24,5% (n.82),
- Navisworks 12.2% (n.41),
- CosteX 7.2% (n.24)

Did you have any experience with BIM before this course?

- Yes 39% (n.143)
- No, only with 2D AutoCAD 32.7% (n.119)
- Not at all 30% (n.111)

If yes, since when are you using BIM?

- Since last semester 34.9% (n.59)
- Since last year 39.1% (n.66)
- Since year one or two 22.5% (n.38)
- Since before Uni. 3.6% (n.6)

At the end of semester, we have received some positive feedback from students. For example, one of the students indicate:

"The assignment posed as a challenge, given I had no prior experience with running these programs, but I found it a nice way to learn Revit and familiarise myself with it and programs like it. It is something I can definitely see myself using in the future workplace."

Similarly, another student mentioned positive feedback about learning both for BIM software and the project context:

"I have found this assignment/exercise very interesting, not only in familiarising myself with the current Metro Tunnel Infrastructure projects, but also gaining greater knowledge of BIM software applications."

Taking technical learning experiences on board, the next heading presents a decision tool for investment and deployment setup.

5. PROMETHEE a method of developing the decision support system

Multi-criteria decision-making methods are appropriate methods for comparing and ranking different alternatives in complicated decision-making environments [15]. We propose the PROMETHEE method to investigate interaction of two different BIM software and three different VR tools. Capabilities of PROMETHEE methodology in different contexts are investigated by [16]. One important advantage of PROMETHEE method is its preference function feature enabling the analyst to define different mathematical functions to simulate the decision-making environment. Different steps of PROMETHEE method procedure are presented on **Figure 1**.

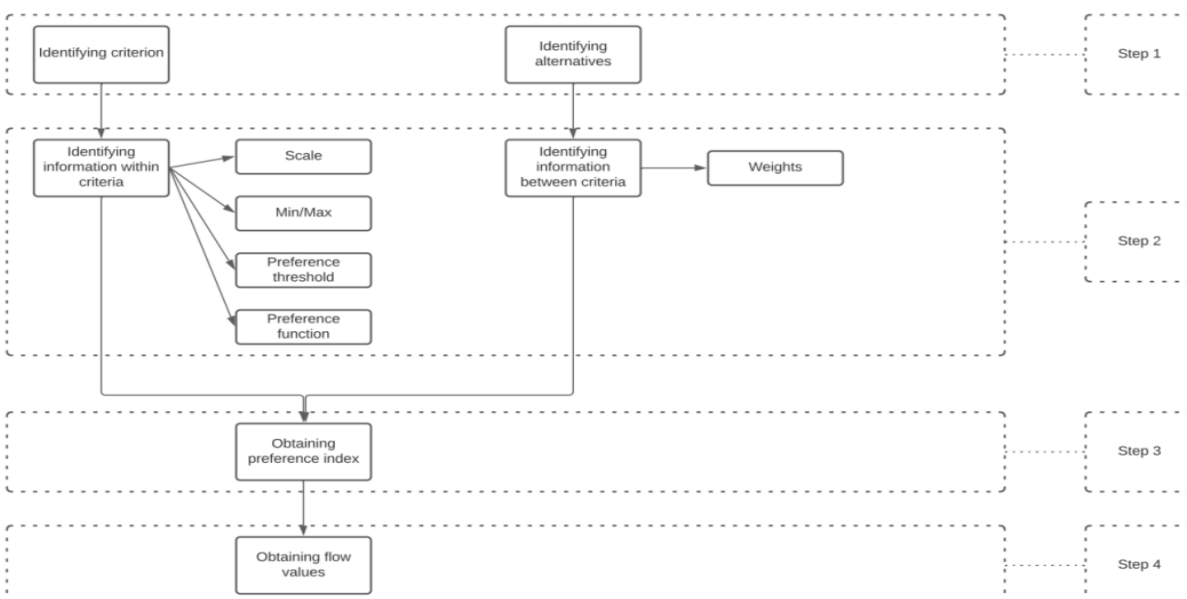

Figure 1. PROMETHEE method procedure

Where a_i as ith alternative belonging to a finite alternative set denoted by $\boldsymbol{A}$, $(a_i \in \boldsymbol{A})$. We show the last alternative by a_I. Let us consider g_j as jth criterion belonging to finite criteria set denoted by $\boldsymbol{G}$. We show the last criterion by J. The performance of alternative a_i pertaining to criterion g_j can be shown by $g_j(a_i)$.

The collection of $g_j(a_i)$ is a $i \times j$ matrix that can be presented as a table and named as evaluation table. **Table** 5 represents an evaluation table for a problem with 4 alternatives and 3 criteria:

Table 5. Evaluation table.

a_i	$g_1()$	$g_2()$	$g_3()$
a_1	$g_1(a_1)$	$g_2(a_1)$	$g_3(a_1)$
a_2	$g_1(2)$	$g_2(a_2)$	$g_3(a_2)$
a_3	$g_1(a_3)$	$g_2(a_3)$	$g_3(a_3)$
a_4	$g_1(a_4)$	$g_2(a_4)$	$g_3(a_4)$

PROMRTHEE method use preference function to make sense of the distance between different alternatives. Brans and Mareschal (1994) identified six different basic preference functions. Different types of preference functions are proposed by different researchers to fulfill complicated research needs, such as the work conducted by Podvezko and Podviezko (2010). A preference value is a real number between 0 and 1 and can be obtained by this formula:

$$P_j(a_i, a_{i'}) = F_j\{d_j(a_i, a_{i'})\}$$

Every preference function is associated with a preference (p) and/or indifference threshold q. If the preference function is Gaussian it is associated with an s value. While preference function allocates a value translating the importance of an alternative pertaining to a criterion from the decision makers perspective the criterion weight identifies the criterion importance. We use w_j to denote the weight of criteria j.

6. Results and Discussion

We have presented lessons learned on deploying BIM-VR in CM education, both from a technical and from an educational perspective. As a third contribution we developed an application to facilitate decision-making for investment and deployment of BIM-VR. The application can be accessed via the following link: https://rbvanalytics.shinyapps.io/software3/. We scripted 364 lines of code to develop the application which can be found in the link below: https://github.com/arazn845/software_1/blob/main/code.

Obtaining values for a decision-making problem can be a controversial task specially when it comes to qualitative criteria [15]. In this early pre-pilot study, we have both quantitative and qualitative criteria. The value for qualitative criteria is extracted through the existing literature, expert advice and class feedback. To initially test our decision-making application, we have considered different information from tables 1, 2 and following table 6.

Table 6. Hypotheses considered for our initial evaluation.

BIM-VR compatibility	Revit™	Navisworks™	Technical support
Oculus Rift w/	*****	***	**
Gear VR w/	*****	***	*****
HTC View w/	*****	****	**
Oculus w/	****	*****	*****
Gear VR w/	*****	**	*****
HTC Vive w/	****	*****	**

The outcomes of initial evaluation are presented in table 6 following by the explanation of notations in table 7. The results indicate that using Revit and Gear VR as well as Revit and Oculus Rift are the best options in the investigated setting. It is worth to note that the outcome of a decision-making process is highly context specific. Different criteria and alternatives could have different values in different contexts. For example, due to financial issues cost can be or cannot be a binding limitation in a decision-making setting. In another decision-making situation user friendliness can be a crucial criterion due to the user background, for example. The investigated decision-making situation has a generous budget for technology purchase. This matter is reflected by indicating a lower weight for the cost/price aspects. In another case, the budget related criterion may be tight, so a higher wight should be allocated. Hence, the results of the analysis would change in the favour of cheaper alternatives. Our case study demanded a considerable weight for “ease of use” factor due to significance of this factor in an educational environment. Nevertheless, consider if the targeted population has enough technology background with the potential software and/or hardware, the weight of these criterion would crucially drop, and it would lead to a tangible change in the alternatives ranking.

Table 7. Evaluation outcomes, Tables a (1) and b (2).

Evaluation table 1

	VR, BIM user friendlyness	VR, BIM ease of use	VR technical support	VR tool Price	VR RAM requirement	VR 360 degree range	VR field of view	VR tool Set up	VR power usage	BIM 4D capability	BIM subscription	BIM RAM requirement	BIM space requirements
Revit & Oculus Rift	9	5	9	399	8	1	110	7	4.5	1	450	8	30
Revit & Gear VR	9	2	9	99	4	0	96	9	2	1	450	8	30
Revit & HTC Vive	9	2	9	599	4	1	110	7	3.5	1	450	8	30
Navisworks & Oculus	6	5	4	399	8	1	110	7	4.5	0	170	2	15
Navisworks & Gear VR	5	2	5	99	4	0	96	9	2	0	170	2	15
Navisworks & HTC Vive	7	2	5	599	4	1	110	7	3.5	0	170	2	15
Preference Threshold	2	1	3	50	4	1	20	3	1.2	1	50	4	5
Indifference Threshold	1	0	1	10	0	0	5	1	0.2	0	5	0	1
Weights	6	5	6	3	4	2	2	2	2	5	3	4	4

Evaluation table 2

	VR, BIM user friendlyness	VR, BIM ease of use	VR technical support	VR tool Price	VR RAM requirement	VR 360 degree range	VR field of view	VR tool Set up	VR power usage	BIM 4D capability	BIM subscription	BIM RAM requirement	BIM space requirements
Scale	qualitative	qualitative	qualitative	Quantitative	Quantitative	Yes/no	Quantitative	qualitative	Quantitative	Yes/no	Quantitative	Quantitative	Quantitative
Unit	9 Likert	5 Likert	9 Likert	dollars	GBs	Yes/no	degree	9 Likert	Watts	Yes/no	dollars	GBs	GBs
Preference function	Level	Level	Level	Linear	Linear	Level	Linear	Level	Linear	Level	Linear	Linear	Linear
Min or max	max	max	max	min	min	max	max	max	min	max	min	min	min

7. Criteria of key attributes for selection of BIM-VR

A step further for BIM-VR integration is here discussed and presented. This is a pilot stage that need further testing and empirical validation however, it is already seen as a valuable support for program managers, lecturers, and educations decisions makers. This tool is also meant as a risk management devise to overcome the strengths and risks of integrating BIM and VR as shown in the following Table 4.

Table 8. BIM-VR strategic selection criteria.

Criteria	Description
Immersivity	Selection according to their cross-platform compatibility
Functionality	Existence of an active community support
Affordability	Free educational license
Specifications	Industry demand
System requirements	Software functions and features
User interface	Graphic interface

This study has taken 3D and 4D BIM functions in Revit mainly, however Rhino, SketchUp Pro and Autodesk Formit have been used for 3D modelling, whereas for 4D modelling Navisworks and Synchro Pro for 4D have been used.

8. Conclusion

Construction industry is currently being transformed mainly by the concepts and technologies of Industry 4.0 such as BIM and VR. To address the requirements of the industry 4.0, universities and educational institution worldwide have started implementing these tools and concepts into the construction management curriculum. However, the integrated approach to the implementation of these tools has received far less attention. Therefore, this study has two main aims. Firstly, to share the lessons learned and strategies during the implementation of BIM-VR in an educational context. Secondly, to develop a decision-making system to support the practitioners during the process of BIM-VR implementation. The study reveals that the most key functions of integrated BIM-VR for construction management education include design visualisation, defect identification, safety, material management, maintenance and facility management, creation of bills of quantities and project scheduling. It is also discussed that there are several BIM software and VR tools in the market. The selection of these tools and the contextual factors render this to a complex decision-making process.

Hence, this study develops a decision support system in the form of an online application which is publicly available. The online application is developed based on the PROMETHEE methodology to facilitate the complex decision-making process during the implementation of integrated BIM-VR in the educational contexts. The main strength of the application lies in its flexibility to account for different context. This is addressed by considering different weights for various decision-making criteria/factors. In our future studies, we further test our decision-making application in different educational settings.

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