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Design and Evaluation of a Virtual Reality Property Business Simulation with an Embedded Building Cost Estimation Module

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Abstract:

This study designs and evaluates a virtual reality property business simulation, SmartRoom, whose central feature is an embedded building cost estimation module. Existing virtual reality applications for the property sector stop at visualisation and do not produce a validated cost figure while a design is being explored, so learners of construction cost estimation cannot observe the spatial consequences of their decisions. Following a design science research framework, the artefact was evaluated on three dimensions: cost estimation accuracy, technical performance, and usability. Accuracy was measured against conventional bill-of-quantity calculations on ten building scenarios using mean absolute percentage error. Technical performance was recorded through in-application telemetry at up to eight concurrent users. Usability was measured on thirty participants using the System Usability Scale and the User Experience Questionnaire, with discomfort measured using the Simulator Sickness Questionnaire. The parametric mode obtained a mean absolute percentage error of 7.02 percent and the quantity-based mode 2.14 percent, both within the tolerance of their respective estimate classes. All performance parameters met their thresholds, the System Usability Scale score was 82.00, and all user experience scales were positive. Simulator sickness rose markedly after use and is reported as the principal limitation. Learning effectiveness was not tested.

Keywords: building cost estimation; property business simulation; usability; virtual reality

Introduction (مقدمة)

Construction cost estimation is taught largely through two-dimensional drawings. Learners compute quantities from plans and sections and multiply them by unit prices, without being able to observe the spatial object those quantities describe. The relationship between a design decision and its cost consequence therefore remains abstract, while opportunities to practise on real projects are limited by cost, permission, and site access.

Virtual reality has been applied to the property sector for some time. Reported applications provide virtual tours of housing units and present design alternatives in an immersive form, and immersive environments have been used in vocational and higher education to support spatial and design skills. These studies establish that immersive environments can be built and accepted by users.

Three gaps remain. First, existing property applications stop at visualisation and do not produce a cost figure while a design is being explored, so the learner still leaves the environment to perform the calculation. Second, they are predominantly single-user, which removes any opportunity to practise explaining or negotiating a cost structure with another party. Third, and most consequential for a tool intended to produce numbers, none of the reviewed studies reports how accurate its output is against a conventional bill-of-quantity calculation.

This study addresses those gaps by designing SmartRoom, a virtual reality property business simulation with an embedded building cost estimation module, and by evaluating the artefact on three dimensions. The objective of this study is to determine the cost estimation accuracy of the module, the technical performance of the environment under multi-user load, and its usability among target users. The scope is confined to the design and evaluation of the artefact; its effectiveness in improving learning outcomes was not tested and is not claimed.

Method (منهج)

This study follows a design science research framework, in which the artefact itself is the research output and is evaluated against criteria established before evaluation begins. Five activities were carried out: explicating the problem, defining requirements, designing and developing the artefact, demonstrating it, and evaluating it.

System Design

The system is organised in four layers. The client layer runs on standalone head-mounted displays and is built with a game engine and its interaction toolkit. The session layer uses a listen-server topology in which one participant device also acts as the server, and state is replicated through networked variables and remote procedure calls. The cloud layer provides relay, lobby, and voice services. The data layer exposes a REST interface that stores design records and telemetry in a relational database.

The cost estimation module operates in two modes. The parametric mode computes cost from floor area, number of storeys, and unit price, applying a location factor to material cost and a roof complexity factor to labour cost, and runs continuously as the design changes. The quantity-based mode reads work volumes directly from the geometry of the model, maps them onto ten work groups, and prices each item according to the Indonesian unit price analysis standard.

Participant Characteristics

Usability was evaluated with thirty participants drawn from civil engineering, building engineering education, and architecture programmes. All participants completed the scenario sequence and the questionnaires in full. The group was homogeneous, with 93.33 percent from three closely related programmes and 70 percent reporting prior experience of virtual reality.

Research Design and Measures

Four evaluations were conducted, each with a criterion set in advance. Functional behaviour was verified through black box testing. Cost accuracy was measured on ten building scenarios against conventional bill-of-quantity calculations prepared using the same unit price basis, expressed as mean absolute percentage error so that it can be compared with the tolerance bands of the estimate classification. Technical performance was recorded through in-application telemetry at two, four, and eight concurrent users, with latency measured from the client side. Usability was measured with the System Usability Scale and the User Experience Questionnaire, and discomfort with the Simulator Sickness Questionnaire administered before and after the session.

Result (نتائج)

The artefact comprises 66 three-dimensional assets and twenty functional requirements, verified through 46 black box test cases across seven functional groups; all cases produced the expected output, exceeding the 95 percent criterion. This figure reflects conformance to specification rather than absence of defects, since testing was performed by the developer.

Table 1 reports the relative error of both estimation modes across the ten scenarios. The parametric mode obtained a mean absolute percentage error of 7.02 percent and the quantity-based mode 2.14 percent, both below the tolerance of their respective estimate classes.

Table 1. Relative error by scenario and estimation mode

Scenario	Building type	Parametric (%)	Quantity (%)
S-01	Type 36, single storey	2.57	1.51
S-02	Type 45, single storey	1.36	0.87
S-03	Type 54, single storey	3.31	1.61
S-04	Type 60, single storey	6.54	2.01
S-05	Type 70, two storeys	6.85	1.67
S-06	Type 90, concrete roof	10.89	2.63
S-07	Type 100, two storeys	8.17	2.12
S-08	Type 45, rural location	3.37	1.25
S-09	Shophouse, two storeys	13.85	3.89
S-10	Small commercial unit	13.27	3.82
MAPE		7.02	2.14

The pattern of these errors is shown in Figure 1. The parametric error rises as the building departs from a simple single-storey dwelling, whereas the quantity-based error remains flat across the same range.

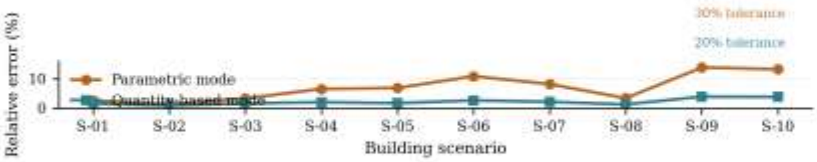

Figure 1. Relative error of both estimation modes across ten scenarios

Table 2 reports the technical performance at increasing concurrency. All eight parameters met their thresholds at the highest load of eight concurrent users.

Table 2. Technical performance at increasing concurrency

Parameter	Criterion	2 users	4 users	8 users
Frame rate (fps)	≥ 72	89.1	85.6	78.2
Frame time (ms)	≤ 13.9	11.2	11.7	12.8
Round trip time (ms)	≤ 100	39	48	63
Jitter (ms)	≤ 30	5	8	14
Packet loss (%)	≤ 2	0.1	0.3	0.9
Motion-to-photon (ms)	≤ 20	15	16	18
Memory (MB)	≤ 3000	1765	2054	2518
Scene load time (s)	≤ 10	6.4	6.8	7.2

The System Usability Scale produced a mean of 82.00, exceeding the criterion of 68, with all participants in the acceptable band. The distribution of scores is reported in Table 3.

Table 3. System Usability Scale results (n = 30)

Statistic	Value
Mean	82.00
Standard deviation	5.06
Minimum	72.5
Maximum	90.0
Median	82.50
Grade	B (acceptable)
Grade A / B / C	4 / 16 / 10

The six User Experience Questionnaire scales are reported in Table 4, all of them positive. Two scales reached the excellent benchmark category and four the good category.

Table 4. User Experience Questionnaire scale means (n = 30)

Scale	Mean	SD	Benchmark
Attractiveness	1.68	0.33	Good
Perspicuity	1.68	0.55	Good
Efficiency	1.59	0.32	Good
Dependability	1.52	0.44	Good
Stimulation	1.73	0.44	Excellent
Novelty	1.62	0.40	Excellent

The Simulator Sickness Questionnaire rose from 17.20 before the session to 68.19 after it, with every participant exceeding the tolerability threshold. Expert validation averaged 94.3 percent across a media and a subject-matter expert.

Discussion (مناقشة)

The results answer the three objectives set in the introduction. On accuracy, both modes met the tolerance of their estimate classes, and the pattern of the errors is more informative than their magnitude. The parametric error rises monotonically as the building departs from a simple single-storey dwelling, from 1.36 percent at S-02 to 13.85 percent for the shophouse, whereas the quantity-based error remains flat. Had the quantity-based mode also relied on an area multiplier, both curves would have risen together; the difference in slope is therefore evidence that the two modes compute by different means.

The single over-estimate, S-08, is also the only rural scenario, and the cause can be traced to a location factor that scales the entire material cost uniformly while, in practice, many materials are priced nationally. Deriving location factors empirically from regional price data is the most consequential improvement identified by this study.

On technical performance, the steepest degradation occurs between four and eight users, consistent with the message volume of state replication growing faster than the number of participants, yet all thresholds were still met. On usability, the high System Usability Scale score and uniformly positive user experience scales indicate an acceptable product, although the narrow spread between scales, only 0.21, offers limited guidance for prioritising improvement and is plausibly explained by the homogeneity of the sample.

The most important finding is the level of discomfort. That every participant exceeded the tolerability threshold, while every performance parameter was met, points to the locomotion mode and environment design rather than to rendering performance. This interpretation is reinforced by the expert assessment, in which comfort of use was independently rated the weakest aspect. Comfort settings were subsequently added, but their effect was not measured and remains for future work.

Conclusion (خاتمة)

This study designed and evaluated a virtual reality property business simulation with an embedded building cost estimation module. The parametric mode achieved a mean absolute percentage error of 7.02 percent and the quantity-based mode 2.14 percent, both within tolerance, and the divergence in error pattern confirms that the two modes compute by different means. All technical performance parameters met their thresholds at eight concurrent users, usability reached a System Usability Scale score of 82.00, and expert feasibility averaged 94.3 percent. The principal limitation is discomfort, which rose markedly after use and exceeded the tolerability threshold for every participant. Future work should re-measure discomfort after the comfort revisions, derive location factors empirically, and test learning effectiveness under an experimental design.

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Bibliography ((مراجع

[1] I. Charney, “Three dimensions of capital switching within the real estate sector: A Canadian case study,” Int. J. Urban Reg. Res., vol. 25, no. 4, pp. 740–758, 2001, doi: 10.1111/1468-2427.00342.

[2] S. A. H. bin Syed Mustapa and K. Jusoff, “Facility Management Challenges and Opportunities in the Malaysian Property Sector,” J. Sustain. Dev., vol. 1, no. 2, pp. 79–85, 2009, doi: 10.5539/jsd.v1n2p79.

[3] M. M. Hassan, N. Ahmad, and A. H. Hashim, “Factors Influencing Housing Purchase Decision,” Int. J. Acad. Res. Bus. Soc. Sci., vol. 11, no. 7, 2021, doi: 10.6007/ijarbss/v11-i7/10295.

[4] K. C. Brata, R. J. Silalahi, and A. H. Brata, “Pembangunan Aplikasi Virtual Reality Tur Perumahan Pada Balimbingan Permai Regency (PT. Karya Propertindo Utama),” J. Teknol. Inf. dan Ilmu Komput., vol. 9, no. 7, pp. 1699–1706, 2022, doi: 10.25126/jtiik.2022976775.

[5] I. Miljkovic, O. Shlyakhetko, and S. Fedushko, “Real Estate App Development Based on AI/VR Technologies,” Electron., vol. 12, no. 3, pp. 1–20, 2023, doi: 10.3390/electronics12030707.

[6] H. Matovu et al., “Immersive virtual reality for science learning: Design, implementation, and evaluation,” Stud. Sci. Educ., vol. 59, no. 2, pp. 205–244, 2023, doi: 10.1080/03057267.2022.2082680.

[7] D. Hon, Augmented reality and virtual reality. The power of AR and VR for business, vol. 29. Manchaster: Springer, 1996. doi: 10.3233/978-1-60750-873-1-327.

[8] D. R. D. Eryanto and J. Prestiliano, “Design of learning media for the solar system lesson using animation and virtual reality,” Open Sci. J., vol. 2, no. 1, pp. 1–13, 2017, doi: 10.23954/osj.v2i1.790.

[9] M. K. Saini and N. Goel, “How smart are smart classrooms? A review of smart classroom technologies,” ACM Comput. Surv., vol. 52, no. 6, 2019, doi: 10.1145/3365757.

[10] Y. Tian, B. Zheng, Y. Wang, Y. Zhang, and Q. Wu, “College library personalized recommendation system based on hybrid recommendation algorithm,” Procedia CIRP, vol. 83, pp. 490–494, 2019, doi: 10.1016/j.procir.2019.04.126.

[11] L. F. Rodrigues, A. Oliveira, and H. Rodrigues, “Main gamification concepts: A systematic mapping study,” Heliyon, vol. 5, no. 7, p. e01993, 2019, doi: 10.1016/j.heliyon.2019.e01993.

[12] M. Hitchens and R. Tulloch, “A gamification design for the classroom,” Interact. Technol. Smart Educ., vol. 15, no. 1, pp. 28–45, 2018, doi: 10.1108/ITSE-05-2017-0028.

[13] I. Deliyannis and P. Kaimara, “Developing smart learning environments using gamification techniques and video game technologies,” Didact. Smart Pedagog. Smart Pedagog. Technol. Enhanc. Learn., pp. 285–307, 2018, doi: 10.1007/978-3-030-01551-0_15.

[14] M. Fominykh, A. Smorkalov, M. Morozov, and E. Prasolova-Førland, “Smart Gamification and Smart Serious Games,” Intell. Syst. Ref. Libr., vol. 84, pp. 137–171, 2015, doi: 10.1007/978-3-319-14645-4.

[15] K. G. Kim et al., “Using immersive virtual reality to support designing skills in vocational education,” Br. J. Educ. Technol., vol. 51, no. 6, pp. 2199–2213, 2020, doi: 10.1111/bjet.13026.

[16] R. F. Arif and H. A. Rosyid, “Pengembangan aplikasi web dengan gamifikasi sebagai media pendukung pembelajaran untuk mata pelajaran pemrograman dasar,” Tekno, vol. 29, no. 2, p. 161, 2019, doi: 10.17977/um034v29i2p161-176.

[17] E. Gabarron, T. Schopf, J. A. Serrano, L. Fernandez-Luque, and E. Dorronzoro, “Gamification strategy on prevention of STDs for youth,” Stud. Health Technol. Inform., vol. 192, no. 1–2, p. 1066, 2013, doi: 10.3233/978-1-61499-289-9-1066.

[18] P. Hodgson et al., “Immersive Virtual Reality (IVR) in Higher Education: Development and Implementation,” BJET Br. J. Educ. Technol., pp. 161–173, 2019, doi: 10.1007/978-3-030-06246-0_12.

[19] Mustafa Ayobami Raji, Hameedat Bukola Olodo, Timothy Tolulope Oke, Wilhelmina Afua Addy, Onyeka Chrisanctus Ofodile, and Adedoyin Tolulope Oyewole, “Business Strategies in Virtual Reality: a Review of Market Opportunities and Consumer Experience,” Int. J. Manag. Entrep. Res., vol. 6, no. 3, pp. 722–736, 2024, doi: 10.51594/ijmer.v6i3.883.

[20] M. Farshid, J. Paschen, T. Eriksson, and J. Kietzmann, “Go boldly!: Explore augmented reality (AR), virtual reality (VR), and mixed reality (MR) for business,” Bus. Horiz., vol. 61, no. 5, pp. 657–663, 2018, doi: 10.1016/j.bushor.2018.05.009.

[21] M. Camacho, “David Kelley: From Design to Design Thinking at Stanford and IDEO,” She Ji, vol. 2, no. 1, pp. 88–101, 2016, doi: 10.1016/j.sheji.2016.01.009.

[22] J. Kiruthika, S. Khaddaj, D. Greenhill, and J. Francik, “User Experience Design in Web Applications,” Proc. - 19th IEEE Int. Conf. Comput. Sci. Eng. 14th IEEE Int. Conf. Embed. Ubiquitous Comput. 15th Int. Symp. Distrib. Comput. Appl. to Business, Engi, pp. 642–646, 2017, doi: 10.1109/CSE-EUC-DCABES.2016.253.

[23] M. Videnovik, T. Vold, L. Kionig, and V. Trajkovik, “Design thinking methodology for increasing quality of experience of augmented reality educational games,” 2019 18th Int. Conf. Inf. Technol. Based High. Educ. Training, ITHET 2019, 2019, doi: 10.1109/ITHET46829.2019.8937385.

[24] E. R. Hayes and I. A. Games, “Making Computer Games and Design Thinking,” Games Cult., vol. 3, no. 3–4, pp. 309–332, 2008, doi: 10.1177/1555412008317312.

[25] M. Zyda, "From visual simulation to virtual reality to games," Computer (Long. Beach. Calif)., vol. 38, no. 9, pp. 25–32, 2005, doi: 10.1109/MC.2005.297.

[26] J. A. Widjaja, L. Jefferson, M. Ferdinand, B. Siahaan, A. Chow, and J. A. Widjaja, "Utilizing Game Development Life Cycle Method to Develop an Educational Game for Basic Mathematics Using Unity 2D Game Engine," vol. 1, no. 1, pp. 20–30, 2024, doi: 10.55123/ijisit.

[27] D. Trenholme and S. P. Smith, "Computer game engines for developing first-person virtual environments," Virtual Real., vol. 12, no. 3, pp. 181–187, 2008, doi: 10.1007/s10055-008-0092-z.

[28] M. Mustofa, J. L. Putra, and C. Kesuma, "Penerapan Game Development Life Cycle Untuk Video Game Dengan Model Role Playing Game," Comput. Sci., vol. 1, no. 1, pp. 27–34, 2021, doi: 10.31294/coscience.v1i1.158.

[29] R. Roedavan, B. Pudjoatmodjo, Y. Siradj, S. Salam, and B. Q. D. Hardianti, "Serious Game Development Model Based on the Game-Based Learning Foundation," J. ICT Res. Appl., vol. 15, no. 3, pp. 291–305, 2021, doi: 10.5614/ITBJ.ICT.RES.APPL.2021.15.3.6.

[30] J. Pandey, A. V. Singh, and A. A. Alabri, "Proposing a Hybrid Methodology for Game Development," 2018 7th Int. Conf. Reliab. Infocom Technol. Optim. Trends Futur. Dir. ICRITO 2018, pp. 142–146, 2018, doi: 10.1109/ICRITO.2018.8748360.