Visualization of BIM Models with Augmented Reality

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Abstract

The Architecture, Engineering & Construction (AEC) industry is known for its inefficiency and lack of digitalization of construction processes. To improve in these areas, the construction industry is increasingly turning to Building Information Modeling (BIM), which creates 3D building data and enables information sharing among project stakeholders. While BIM is increasingly used, its application is often limited to the planning and design phases of buildings. BIM systems and thus access to digital information have hardly been used in the construction phase so far

This paper investigates the usability of a practical system for visualizing BIM models using augmented reality (AR) in the construction phase.

For this purpose, a system of IT tools was developed, which are often used in this area. In an experimental design, participants were asked to perform tasks with this system on a construction site.

To measure the system's usability, well-known, validated metrics were used. In addition, possible connections with prior experience in BIM or AR regarding the usability of the developed system are examined.

The results show a mixed picture regarding the system's usability. Any connections with previous BIM or AR experiences also do not show any clear tendencies.

Keywords

Building Information Modeling, Augmented Reality, Mobile Augmented Reality, System Usability Scale, Handheld Augmented Reality Usability Scale (HARUS), Empirical Study

1. Introduction

Advancing digitalization has greatly changed how buildings are planned and built over the past few decades. A decisive factor in this development is the growing dissemination and use of Building Information Modeling (BIM). BIM goes far beyond the use of computer-aided design (CAD), which remains the predominant tool for digitization. BIM enables a comprehensive representation of 3D building data and the integration of information on components, materials, and systems [1]. "Nearly half of the survey respondents report that BIM is used on between 76% and 100% of their projects, with almost a quarter (23%) reporting that all of their projects incorporate BIM processes" [2]. It acts as a concept that allows all project participants to work together on a virtual model, resulting in more precise and efficient collaboration [3].

Although BIM has revolutionized the design and design phase of buildings, the benefits remain largely untapped in the construction phase. In particular, the process has not yet been effectively implemented in construction site monitoring and coordination [4]. A promising way to solve this problem is the visualization of BIM models using augmented reality (AR). AR is considered a promising technology for effectively bringing BIM to the construction site and serve as an extension of BIM [5]. Since this approach has so far been little used in practice, a pilot study will be carried out to gain further insights into its use.

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The objectives of this project are twofold:

a) to be able to make statements regarding the usability of the system
b) to uncover possible connections with previous experiences in the areas of BIM or AR concerning the usability of the developed system

The pilot study must be designed to reflect real-world conditions and account for actual project circumstances.

Based on these results, improvements to the overall system can be derived. In a further step, this approach can be integrated into various training courses in Architecture, Engineering & Construction (AEC). This topic can also be used as a part of continuing education courses in the field of work-based learning or for the development of micro-credentials.

2. Theoretical Background

In this section, the theoretical background for the pilot study's central content is presented.

2.1. Integration of BIM and AR

BIM is a process-oriented approach to planning, designing, and constructing buildings using digital 3D models [6]. The models are not only used to represent geometries, but also to exchange information.

The most widely cited foundational definition comes from Succar et al. [7], who define BIM as "a set of interacting policies, processes and technologies producing a methodology to manage the essential building design and project data in digital format throughout the building's lifecycle" [7]. This definition captures the three pillars — technology, process, and policy — that recur across the literature.

On the standards front, ISO 19650 [8] represents the current international standard for information management using BIM. The ISO 19650 series is the international standard for information management using BIM throughout the lifecycle of built assets, from strategic planning through operation and disposal. It consists of two parts:

Part 1 „Concepts and Principles" establishes the overarching concepts and principles for information management using BIM across the whole life cycle of built assets (from strategic planning through operation and disposal). It also provides a common vocabulary and high-level framework that Part 2 applies to projects and assets.

Part 2 "Delivery phase of assets" defines how to manage information using BIM during the project delivery phase, from tender to close-out, and operationalizes the concepts from Part 1 with roles, inputs, outputs, and a step-by-step process.

Based on this definition, it is already clear that BIM can be used throughout the entire life cycle of buildings. Starting with planning and execution, BIM can also be used to improve the maintenance and management of buildings [9].

AR combines digital information with the real world, allowing users to perceive it in real time [10]. Unlike virtual reality (VR), which puts users in a completely artificial environment, AR inserts virtual objects into the real world. Users can continue to perceive their physical surroundings while additional information, images, or animations are superimposed [11].

Since AR represents the real environment with a virtual overlay [12], it lies closer to the fully real world than to the fully virtual world [12].

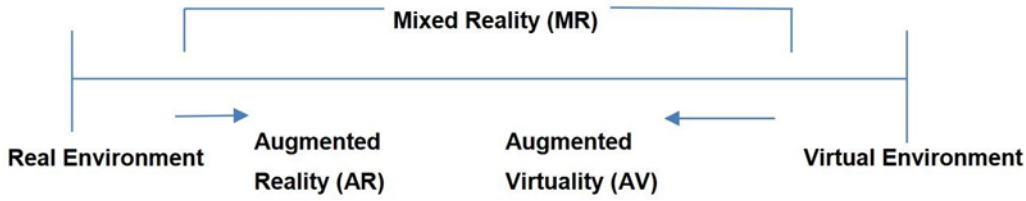


Figure 1: Simplified representation of the virtuality continuum [13]

Cameras and sensors record the user's position and orientation in the room. The digital data is then positioned to match the real environment exactly. AR is defined by the following three properties [14]:

1. Combination of real and virtual worlds
2. Real-time interaction
3. Display in 3D

The integration of AR with BIM has the potential to transform the AEC industry. To achieve improvements in efficiency and productivity. AR enables the integration of digital information with the physical world, making project management and coordination much easier [1]. Through the visual representation, all project participants can gain a better understanding of the tasks and goals.

2.2. Test Metrics

Two metrics, the System Usability Scale (SUS) and the Handheld Augmented Reality Usability Scale (HARUS), are used to measure usability.

SUS is a widely used metric for measuring the perceived usability of a system or product. It was developed in 1996 to create a standardized way to record subjective assessments of a system's effectiveness, efficiency, and satisfaction [15]. It provides a reliable, high-level subjective view of perceived usability through a 10-item survey. When evaluating the questionnaires, an overall score is calculated on a scale of 0 to 100, with higher scores indicating greater user-friendliness [15].

Numerous studies have confirmed the validity and reliability of the SUS and have successfully applied it across different contexts and user interfaces [16]. The following figure shows the assessment of a system's usability based on its calculated SUS total score.

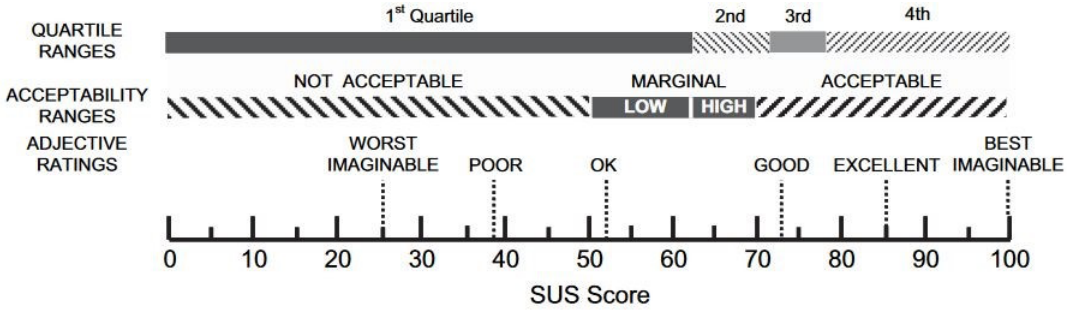


Figure 2: Classification of SUS Overall Ratings [17]

A specific metric is used to evaluate the user-friendliness of AR systems [18]. HARUS is a specific metric for evaluating the usability of handheld augmented reality systems [19].

It is an adapted instrument based on the principles of the SUS, but was developed specifically for Mobile Augmented Reality (MAR) applications.

To make a comprehensive statement about the overall system's usability, it is recommended to use SUS in combination with HARUS [20]. HARUS is a standardized questionnaire [21] consisting of 16 statements answered on a 7-point Likert scale. The focus is on two concepts [22]:

1. Manipulability: How easy is the system to handle? This involves ergonomic factors such as device weight, arm fatigue, and control precision.
2. Comprehensibility: How well is the information displayed, readable, and understandable? This includes visual factors such as text size, refresh rate (flicker), and presentation consistency.

By combining HARUS with SUS, statements can be made about the overall user-friendliness and potential problems of a system, as well as about AR-specific properties [20].

3. Design of the Empirical Study

To empirically examine the entire system, an experiment was conducted in cooperation with the facility management department of a large company. This department looks after the company's internal buildings throughout their entire life cycle, from planning and construction to maintenance. The engineering groups in the respective departments handle planning, construction, and conversion of buildings.

The engineering groups consist of technical drafters, technicians, and project managers who act as client representatives and coordinators. BIM was introduced in these areas five years ago and has been used ever since. The BIM software is primarily used by technical draftsmen, with the technicians and project managers then using the BIM output for their tasks. These groups represent a potential user base, as they are already actively using BIM. Given familiarity with BIM, the main focus of the test can be on integrating AR.

Based on the considerations mentioned above, the test will be conducted with participants from the following engineering groups within the facility management department: Construction Technology, Building Services, and Electrical Engineering.

3.1. Hypotheses

Based on the study's objective, the following hypotheses can be derived, with only hypothesis H0 cited in each case.

1. Hypothesis 1: There is no difference in the usability of the overall system (SUS) between the different disciplines of the civil engineering industry.
2. Hypothesis 2: There is no correlation between BIM experience and the usability of the overall system (SUS).
3. Hypothesis 3: There is no correlation between AR experience and the usability of the MAR system (HARUS).
4. Hypothesis 4: There is no correlation between the usability of the MAR system (HARUS) and the usability of the entire system (SUS).

3.2. Participants

Based on the above considerations, the test will be carried out with 20 people from the Engineering Building Technology, Engineering Building Services, and Engineering Electrical Engineering groups, which are part of the Facility Management Department.

3.3. Test System

A test system for a usability test represents the environment in which test subjects interact with the system. It is to be designed to reflect real usage situations as accurately as possible, generating realistic and reliable feedback. Autodesk Revit is used to create the building's BIM model. The building comprises three sub-models, each with a specialist area: construction, building, and electrical engineering. All models are generated at the LOD400 level of detail, which is required for model superimposition[23].

The models are then exported in the Industry Foundation Classes (IFC) format, an open standard for data exchange in the construction industry[23]. The IFC 2x3 version is chosen for export, as it is supported by both Revit and Gamma AR. Once exported, the three models are transferred to the Autodesk BIM 360 cloud platform. This platform is directly linked to the Gamma BIM portal, so new or modified models are automatically synchronized between the two platforms.

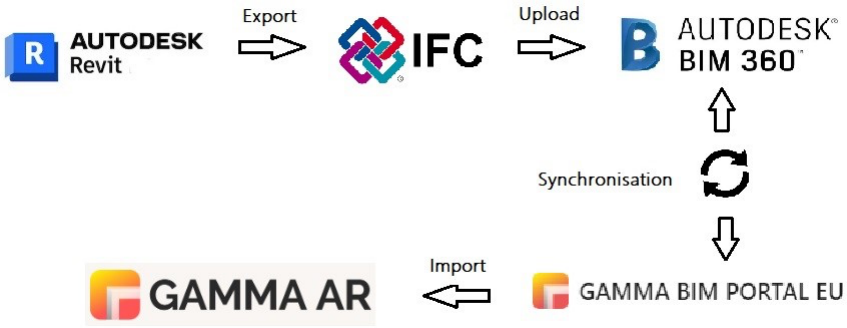


Figure 2: Structure of the test system

Gamma AR is used to visualize the BIM models within the building. The smartphone application is used for the test. This system is prepared before the usability test and remains constant throughout all test runs to ensure that the collected data is authentic and unbiased.

3.4. Tasks for the Participants

The tasks cover the entire area of application of the system and are to be evaluated using the subsequent questionnaires. The tasks are easy at the beginning and get progressively harder. The tasks begin with a general introduction to the application, move on to tasks in the test person's specialist area, and conclude with tasks across all specialist areas.

1. Task 1: Open the Gamma AR application and load the BIM model of your department from the Gamma BIM Cloud.
2. Task 2: Select the appropriate floor of the model and position the model based on the reference object selected on the plan.
3. Task 3 (Figure 4): Move around the room and get used to the superimposition of the BIM models. Next, adjust the overlay intensity from the default 50% to 0%. After that, increase the intensity to 100%, then revert it to the original 50%.
4. Task 4: Use the overlay intensity to check whether the position of already performed services corresponds to the BIM model.
5. Task 5: Use the visualization to check whether all services have been performed in your department.
6. Task 6: Check for inventory collisions with planned deliverables.
7. Task 7: Please go to an area of the building where all three trades of construction, building, and electrical engineering are available and reposition the BIM model.
8. Task 8: Add the BIM models from the other two departments to your model by loading them from the Gamma BIM Cloud.
9. Task 9: By visualizing the overall model, identify areas where coordination between departments is necessary.
10. Task 10: Please perform a collision check between the departments using the added models

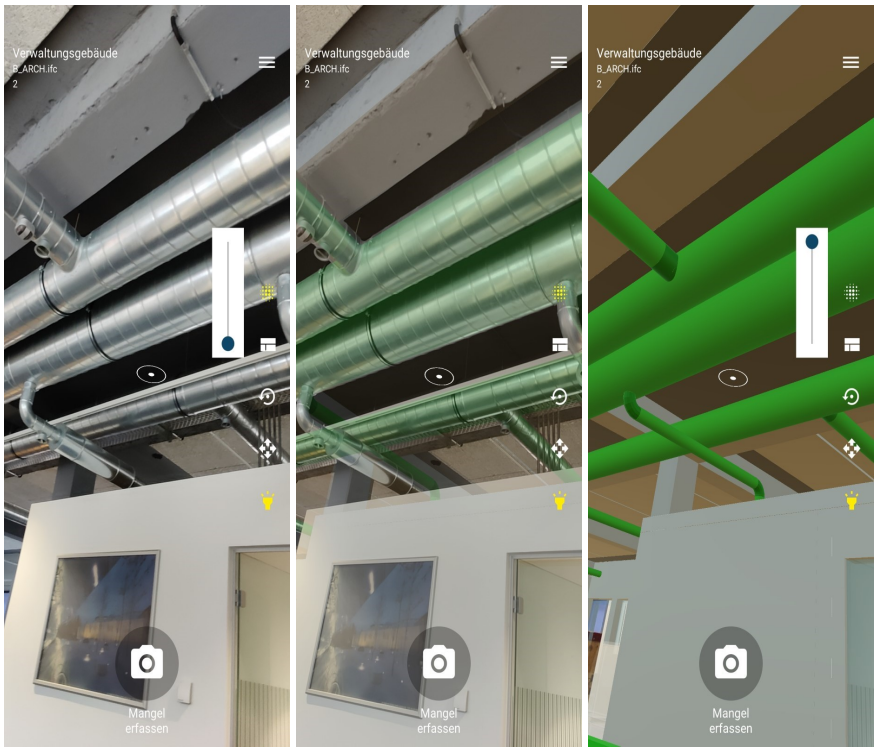


Figure 3: Task 3 – right: overlap 0%, middle: overlap 50%, left: overlap 100%

3.5. Procedure of the Study

The study was carried out in the following steps:

1. Welcoming the participants
2. Questionnaire on demographic data, as well as previous experiences with BIM and AR
3. Working through a tutorial (created with Gamma AR) that gives an overview of the basic functions of the application. Any questions that may arise will be clarified
4. Working through the tasks
5. Filling out the SUS questionnaire
6. Completing the HARUS questionnaire

4. Results

This section describes the results of the analysis of the collected data. First, the descriptive statistics are presented, followed by the results of the two metrics, SUS and HARUS. The validation of the hypotheses closes this section.

4.1. Descriptive Statistics

A total of 20 people took part in this study. The participants' age structure is shown in Table 1:

Table 1
Participants – Age

Age range (years)	Frequency
25–30	2
30–35	1
35–40	4
40–45	5
45–50	2
50–55	3
55–60	2
60–65	1

15 males and 5 females participated in this study. Although this distribution does not correspond to the proportions of the entire population, it is not uncommon in the construction industry. While a 35% female quota still prevails in architecture, the construction industry as a whole shows an even greater disparity [69]. Here, the proportion of female employees is only between 10% and 13%. Therefore, the participants nevertheless represent a representative sample of users in the construction industry.

Table 2 depicts the highest educational attainment of the participants. The majority of respondents said they had either completed an apprenticeship or had obtained a high school diploma. In the test group, two participants have bachelor's degrees, and one has a master's degree.

Table 2
Participants – Highest level of Education

Highest Education	Share
Apprenticeship (completed)	45%
Bachelor	10%
High School Diploma	40%
Master	5%

45% of the participants work in Construction Technology departments, 30% in Building Services and 25% have their professional background in Electrical Engineering.

The test group consists of professionals who are already working in an environment that has been following the BIM approach for several years. This long-standing involvement in a BIM-oriented environment is clearly reflected in the self-assessment of their BIM experience (Table 3)

Table 3
Participants – BIM Experience

BIM Experience	Share
no experience	10%
little experience	25%
Moderate experience	20%
a lot of experience	20%
a great deal of experience	25%

A huge majority of 80% stated that they had no previous experience with AR (Table 4).

Table 4
Participants – AR Experience

AR Experience	Share
no experience	80%
little experience	10%
Moderate experience	5%
a lot of experience	5%

4.2. Results of the Test Metrics

The calculation of the total score of the SUS reveals the following results (Table 5):

Table 5
Results – SUS

Key figure	Value
Minimum	18
Mean	58.8
Median	57.5
Maximum	88

The present study reported an average SUS score of 58.8, with a median of 57.5. A look at Table 5 reveals that the system is only in the low marginal range on the acceptance scale. This placement suggests that the system still faces significant challenges, even though users do not fundamentally reject it. The mean of 58.8 places the system in the upper segment of the first quartile, indicating clear potential for improvement. With a maximum of 88 and a minimum of 18, the evaluation shows considerable dispersion. In particular, the lowest value of 18 indicates that users may encounter serious problems with the system. Although the SUS score of 58.8 indicates a system that still needs improvement, it is still in the OK range of the scale.

Table 6
Results – HARUS

Key figure	Value
Minimum	53
Mean	66.1
Median	67.2
Maximum	78

The evaluation of the HARUS questionnaires (Table 6) results in a mean value of 66.1 and a median of 67.2. Compared to the SUS results, the average value is 7.3 points higher, and the median is 9.7 points higher. This suggests that the MAR system was rated more positively than the system as a whole. This suggests that the identified difficulties are likely not primarily in the MAR area and that improvements are primarily needed elsewhere. Furthermore, the HARUS values exhibit a much narrower fluctuation range than the SUS values. While the minimum value for SUS was only 18, HARUS has a much higher minimum value of 53.

4.3. Validation of the Hypotheses

In the following section, the hypotheses are validated. This is done using various correlation analyses conducted with IBM SPSS Statistics [70].

Hypothesis 1 (Table 7): To test this hypothesis, the variables SUS score and the subject area are examined for correlation. The SUS score is a metric, whereas the subject area is a nominal variable. For this reason, the correlation is examined using the Pearson Chi-Square test. The chi-square test results in a p-value of 0.595. From this, it can be concluded that the department does not have a significant connection. The application's usability is therefore independent of the specific subject area.

Table 7
Validation of Hypotheses 1

	Value	df	Asymptotic Sig. (2-sided)
Pearson Chi-Square	23.667	26	.595
Likelihood Ratio	28.821	26	.319
Linear-by-Linear Association	.554	1	.457
Number of Valid Cases	20		

Hypothesis 2 (Table 8): To test this hypothesis, the variables BIM experience and the SUS Score were analyzed for correlation. The BIM experience was assessed on a Likert scale, so the Spearman correlation is used for the analysis. The calculated correlation coefficient is r = 0.131. An r-value between 0.1 and 0.3 indicates a weak positive correlation. Based on this analysis, hypothesis H1 can be accepted.

Table 8
Validation of Hypotheses 2

		SUS Score	BIM Experience
SUS Score	Correlation Coefficient	1.000	.131
	Sig. (2-tailed)		.582
	N	20	20
BIM Experience	Correlation Coefficient	.131	
	Sig. (2-tailed)	1.000	
	N	20	20

Hypothesis 3 (Table 9): As with the BIM experience, a Likert scale was used to evaluate the AR experience. The HARUS score is a metric value, which is why Spearman's correlation coefficient is used. The calculated correlation coefficient is r = 0.097. An r-value less than 0.1 does not indicate a significant correlation. This suggests that there is no correlation between AR experience and the HARUS score.

Table 9
Validation of Hypotheses 3

		HARUS Score	AR Experience
HARUS Score	Correlation Coefficient	1.000	.097
	Sig. (2-tailed)		.684
	N	20	20
AR Experience	Correlation Coefficient	.097	1.000
	Sig. (2-tailed)	.684	
	N	20	20

Hypothesis 4 (Table 10): In this hypothesis, two metric values are used, the SUS and HARUS scores. For this reason, the variables are set for Pearson correlation. The calculated correlation coefficient is r = 0.508. This indicates a strong positive correlation between the HARUS and SUS

scores. Thus, the alternative hypothesis H1 can be accepted, and the null hypothesis H0 can be rejected.

Table 10
Validation of Hypotheses 3

		HARUS Score	SUS Score
HARUS Score	Correlation Coefficient	1.000	.508
	Sig. (2-tailed)		.022
	N	20	20
SUS Score	Correlation Coefficient	.508	1.000
	Sig. (2-tailed)	.022	
	N	20	20

5. Conclusions

Since HARUS is higher than SUS and HARUS variability is lower, the main usability problems are likely outside the MAR interface. Improvement efforts should therefore target the workflow and integration rather than the AR user interface itself.

The strong positive correlation between HARUS and SUS (r=0.508) suggests that improving AR-specific usability can enhance the overall experience. However, the persistent SUS–HARUS gap indicates parallel work is needed on non-AR elements to realize larger gains.

The lack of a significant association between department and SUS (p = 0.595) indicates that discipline-specific tailoring is not required for core usability fixes. A common set of improvements should benefit construction, building services, and electrical engineering alike.

BIM experience shows only a weak relationship to SUS (r=0.131), and AR experience shows no meaningful relationship to HARUS (r=0.097). Consequently, usability should be improved through design changes and streamlined workflows.

Based on the results of the pilot study, the study's approach can be embedded in AEC curricula and continuing education, including work based learning and micro credentials. These activities support structured upskilling on BIM and AR-supported workflows. The study's task sequence (e.g., loading models from the Gamma cloud, positioning and overlay control, inter-trade aggregation, and collision checks) can be directly adapted into lab exercises, progressing from simple to complex coordination activities that mirror real site workflows.

With 80% reporting no prior AR experience, introductory modules should provide guided exposure to handheld AR, basic manipulability, and information-comprehension tasks before advancing to more complex scenarios.

Short, single session evaluations limit insight into sustained performance. To ensure longitudinal development, continuous on-the-job training cycles and multi-session field exercises should be provided. In particular, work-based learning scenarios can extend knowledge beyond classroom workshops..

6. Limitations and Further Research

This research presents the first study to identify potential applications of BIM and AR within a single company. Thus, several limitations are inherent.

The study involved 20 participants drawn from a single facility management department, which may limit the generalizability of the findings beyond this organizational context. Participants worked in an environment that had followed a BIM-oriented approach for several years, which could bias perceptions of usability relative to BIM novices. Usability was assessed in a single, short-term session following a tutorial and a defined task sequence.

The findings are tied to a specific toolchain configuration (Revit with LOD400 models exported to IFC 2x3, synchronized via BIM 360/Gamma BIM portal, and visualized with the Gamma AR

smartphone app), which may not directly transfer to other platforms or device setups without adaptation. The evaluation focused on a handheld, smartphone-based MAR application, narrowing the applicability of results to other AR form factors and hardware configurations.

Future studies should broaden the participant populations and usage contexts by replicating the experiment with larger, more diverse samples across organizations and project types. Comparative evaluations should assess usability across handheld smartphones, tablets, and head-mounted AR devices to quantify form-factor effects, since the present study focused only on a smartphone-based MAR application.

Research should investigate alternative BIM/IFC pipelines and integration workflows to identify non-AR bottlenecks suggested by higher HARUS scores relative to SUS, indicating issues outside the AR interface itself.

Longitudinal, real-world field trials should be conducted over multiple sessions to observe learning curves, sustained usability, and reliability in ongoing site coordination, addressing the current study's single-session design.

Declaration on Generative AI

During the preparation of this work, the authors used Grammarly to perform a grammar and spelling check. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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