Utilizing Fuzzy Weights for Enhanced User Experience in Virtual Museums

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***Abstract*— In the digital age, the existence and experience of art, history, and culture change worldwide, and the rise of virtual museums ensures that the boundaries are eliminated and interactions with the population diversities are improved for education and culture preservation. This paper analyzes fuzzy weights for personalizing user experiences in virtual museums. Fuzzy weights propose recommendations and subtle content adaptation from user preferences and behaviors to enhance further engagement in the content exposed. Based on a case study of VirtuMuse, we have developed a model to calculate fuzzy weights from user interactions, which are integrated into content management and recommendation systems. User engagement was high, personalization effective and the users were satisfied based on forty university students' evaluation. In conclusion, these findings underscore its effectiveness in matching contents according to individual users' preferences, thereby enhancing their overall experience. Such research highlights the potential for virtual museums to act as preservers of digital cultural heritage and providers of personalized immersive educational experiences.**

Keywords—virtual museums; immersive learning; cultural preservation; fuzzy weights; personalized experience; digital heritage

I. INTRODUCTION

Virtual museums are essential landmarks in art, history and culture changing our perception and understanding in the digital age [1], [2]. They have no fixed sites like conventional museums, yet they can be located anywhere, so that people across the globe can reach out to them even if they cannot personally make it to the museum. It is a technology with vast educational and cultural preservation capabilities [4], [5], [6], [7].

Virtual museums use classrooms to bring history alive before students pivotally. They are engaging and, most importantly, make learners experience exhibits in a manner that inspires learning and holding onto the information within [8], [9]. An online tour through, for example, ancient Egyptian history could feature interactive 3D scans of their artifacts, integrative timelines, and multimedia to contextualize what is more than written about their nefarious mummies in textbooks. It makes it easy to understand and accept, satisfies their desire for knowledge at their own pace, and allows them to engage deeply with many subjects. Virtual museums preserve culture by providing an inexpensive way of preserving artifacts and works of art without necessarily risking the change that would occur due to physical causes [10], [11]. Forgotten through digital preservation, extremely fragile objects can be seen and studied without any decay. This would be accrued because virtual museums can amass artifacts from all institutions worldwide and put up encyclopedic digital exhibitions with an express intent to make people more aware and appreciative of differing cultures.

As usage popularity grows and virtual museums become sophisticated, the need to keep giving users a personalizing and compelling experience becomes paramount [12], [13], [14]. That is where fuzzy weights come in. Grounded on fuzzy set theory, fuzzy weights represent user preferences and behaviors in subtle, flexible ways that are impossible to achieve with prior binary or scalar models. This could be especially appropriate for grasping the complications of user interests within virtual museums. Instead of assuming a simple high versus low interest by a user visiting the exhibit, the fuzzy weights maintain a gradient of interest levels to be listed and processed. This could further enable the system to adjust more precisely to the unique profile of users for their personal and engaging experiences [15], [16], [17], [18], [19].

Fuzzy weights can effectually be used for several aspects of virtual visitation to a museum [20]. They can advise on recommendation systems that include suggestions for relevant exhibits or content conspicuous with the user's inferred preferences. In addition, they dynamically adjust the presentation of content to underline details of exhibits most likely to raise interest in users. Integrated fuzzy weights with interaction design increases user satisfaction concerning the virtual museums significantly.

In this light, this research aims to find ways of using fuzzy weights in the optimization of virtual museum user experiences. Among others, goals include:

- Development of an inclusive model that will assist the derivation of fuzzy weights from user interactions through key behaviors and preferences which can be quantified to represent fuzzy weights. The model will focus on capturing subtle variations in user interest and engagement through detailed analysis of interaction data.
- To integrate fuzzy weights into the virtual museum's content management and recommendation systems: The

goal is to create a dynamic and adaptive environment that responds to individual user preferences. This will ensure that the content and presentation of exhibition recommendations align with users' individually different interests to facilitate further enrichment.

- Test how overall engagements and satisfaction of users with a virtual museum increase based on personalization fuzzy weights from empirical studies and user input. Evaluation metrics would include interaction time with the user, satisfaction ratings, and relevance ratings for recommended content.
- Address possible challenges or limitations on using fuzzy weights: This will err on the side of computational complexities, possibilities of weight assignment biases, and user privacy issues. Its solution would be outlined in this study to help mitigate such challenges, which can ensure the strong and ethical application of fuzzy weights within virtual museums.

The fulfillment of these objectives will contribute to the development of virtual museums and, generally to the preservation of digital cultural heritage. It is in this light that the research, with the knowledge and practical solutions it shall generate, will lead to much more personalized and foreseeably more engaging user experiences for the end-users and further enhancement of access to and appreciation of digital culture artifacts and exhibitions in the digital age.

II. Overview of the Virtual Museum Platform

VirtuMuse, a virtual museum platform, used in this study, is a complex digital space that tries to simulate the experience of a physical museum (Fig. 1). This includes high-resolution imaging, 3D modeling, and interactive multimedia to create a richer, more immersive experience. This gives users the ability to move around the museum with more life-like aggression, in addition to the more standard moving controls that make the environment more interactive. The service hosts a collection of exhibits from ancient Greek artifacts to Egyptian relics to a gallery of paintings, each carefully replicated to offer both close-up views and background details (Fig. 2).

Fig. 1. Start screen of VirtuMuse.

Fig. 2. An excibit from the Egyptian era.

When the virtual museum is accessed, a virtual curator (Fig. 3) presents users with information about the exhibits, helps navigate through the spaces, and also answers different queries. The museum has a circular design to ensure a flow in serial of the exhibits, and there are some other facilities like a cafe, gift shop, and elevator leading to a cinema hall. This allows for a structured virtual museum, replicating an actual museum layout and also incorporating digital modernities that make the experience even livelier.

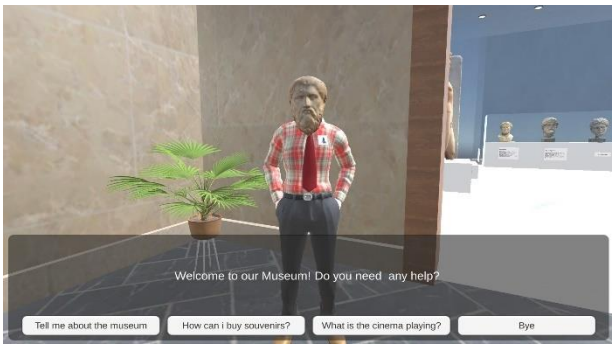

Fig. 3. An agent welocming the visitor.

Time spent on exhibits, user ratings, and navigation patterns are all distilled into fuzzy weights. These byte-level interactions largely determine what the user likes or doesn't like about the museum and are an essential input for personalizing the museum experience:

- Exhibits Time: This will keep track of how much time a user spends looking at any given exhibit. If a video is being watched for longer times, this shows a lot of interest or engagement. These are cloaked into fuzzy weights based on longer viewing times and provide higher rankings to exhibits capturing the user responsibility more accurately as compared to binary or fixed weights.
- Post-show user ratings: These ratings (on a scale of 1-5) are then transformed into fuzzy weights. A higher rating means a higher degree of fuzzy weight, showing lots of likings for the common characteristic.
- Navigation Sequences: How, where, and in what order users navigate the museum is checked against natural exploration paths. Repeated trips to particular parts or exhibitions signal a preference, which is then converted into fuzzy weights again. For example, if a user has been

visiting the Egyptian artifacts section many times, the fuzziness weight for this category is amplified.

Then, the incorporation of fuzzy weights into the Virtual Museum Recommendation and Adaptation Systems (VMRAS) is made in the following three steps:

- Data Aggregation: Consequently, aggregation ensures that all interaction data (in terms of time spent, ratings, navigation patterns) are gathered and analysed to deduce fuzzy weights. These weights are constantly adjusted as the user interacts more with the museum.
- Fuzzy Inference System: A fuzzy inference system is used for processing those weights that are generated and based on these weights, the recommendations are generated. Based on the taught-matrix weighting model and the fuzzy logic-used-matrix weighting system; this system parses the weight inside an nterpretative fuzzy rule and produces which are the most/least relevant exhibits or contents to each user. If, for instance, the system has learned that fuzzy weight on ancient Greek artifacts is high, hence, the system will weigh heavier the classes of exhibits originating as ancient Greek ones in its recommendations.
- Content Adaptation: The content to be presented is acceptance set depending on the fuzzy weights. The displays that interest the user are placed first, and overviews and media resources are accessible. By adapting, the user is more likely to be served with content that suits their preferences, hence their experience with the platform is a lot better.

A range of data collection techniques are used to get a complete picture of user desires and behaviors:

- User Interaction Logs: Recording of detailed logs of user-interaction, including duration on each exhibit, ratings submitted, and navigation paths are recorded automatically. These logs constitute the main database for extracting the fuzzy weights.
- Feedback & surveys: Regular user satisfaction and preference feedback & surveys are performed to gather qualitative data. Overall experience + what the user loved or hated + how we could do better. This commentary complements the quantitative data from interaction logs and gives us some nuanced insights into user behavior.
- Feedback Loops: In-app feedback loops for real-time comments and suggestions as the user makes the way through the museum. Eventually, these fuzzy weights will be transposed but feedback within feedback is used to help pay down these fuzzy weights, which in turn refines the personalization algorithms.

A complete digital environment, the virtual museum platform used in the study is engineered to provide visitors with a highly engaging, interactive, and educational experience. The platform generates personalized content and recommendations using fuzzy weights derived from a peel of user interactions such as exhibit viewing time, user ratings, etc. The integration of fuzzy weights into its systems ensures that every user enjoys a unique experience leading to an improved admixture of engagement and satisfaction at the museum. The fuzzy weight approach was employed using traditional methods for collecting data, including user interaction logs, surveys, and real-time feedback, to refine the personalization process and thus ensuring the effectiveness.

III. Personalization of the User Experience

The implementation of fuzzy weights within the VirtuMuse involves a detailed calculation process designed to capture and utilize user preferences and behaviors for personalized content recommendations and presentations. This process consists of several key stages:

The first step in the fuzzy weight calculation process is defining the criteria that will be used to derive these weights. The criteria were established by a panel of ten academic experts specializing in informatics and culture, and include:

- Interest Level (IL): Measured by the time (in minutes) a user spends on an exhibit. Longer viewing times suggest higher interest.
- Engagement (EN): Determined by user interactions such as zooming in on details, clicking for additional information, or leaving comments.
- Content Relevance (CR): Based on the user's explicit feedback through ratings and preferences indicated during interactions.

Table I presents the membership function for IL, where Low (L) ranges from 0 to 5 minutes, Medium (M) from 5 to 10 minutes and High (H) from 10 to 30+ minutes.

TABLE I. IL Membership function

Fuzzy Weights Membership Function for IL
$\mu_{LOW}(t) = \begin{cases} 1; & t \le 5 \\ 1 - \frac{t-5}{5}; & 5 < t \le 10 \\ 0; & t > 10 \end{cases}$
$\mu_{MEDIUM}(t) = \begin{cases} \frac{t-2}{3}; & 2 < t \le 5 \\ 1; & 5 < t \le 10 \\ 1 - \frac{t-10}{5}; & 7 < t \le 9 \\ 0; & t \le 2 \text{ or } t > 15 \end{cases}$
$\mu_{HIGH}(t) = \begin{cases} \frac{t-5}{5}; & 5 < t \le 10 \\ 1; & t > 10 \\ 0; & t \le 5 \end{cases}$

Table II presents the membership function for EN, where Low (L) ranges from 0 to 2 interactions, Medium (M) from 2 to 5 interactions and High (H) from 5 to 10+ interactions.

TABLE II. EN MEMBERSHIP FUNCTION

Fuzzy Weights Membership Function for EN
$\mu_{LOW}(i) = \begin{cases} 1; & i \leq 2 \\ 1 - \frac{i-2}{2}; & 2 < i \leq 4 \\ 0; & i > 4 \end{cases}$
$\mu_{MEDIUM}(i) = \begin{cases} \frac{i-1}{1}; & 1 < i \leq 2 \\ 1; & 2 < i \leq 5 \\ 1 - \frac{i-5}{2}; & 5 < i \leq 7 \\ 0; & i \leq 1 \; or \; i > 7 \end{cases}$
$\mu_{HIGH}(i) = \begin{cases} \frac{i-4}{1}; & 4 < i \leq 5 \\ 1; & i > 5 \\ 0; & i \leq 4 \end{cases}$

Table III presents the membership function for CR, where Low (L) is a rating from 1 to 2, Medium (M) is from 2 to 4 and High (H) from 4 to 5.

TABLE III. CR MEMBERSHIP FUNCTION

Fuzzy Weights Membership Function for CR
$\mu_{LOW}(r) = \begin{cases} 1; & r \leq 2 \\ 1 - \frac{r-2}{1}; & 2 < r \leq 3 \\ 0; & r > 3 \end{cases}$
$\mu_{MEDIUM}(r) = \begin{cases} \frac{r-1}{1}; & 1 < r \leq 2 \\ 1; & 2 < r \leq 4 \\ 1 - \frac{r-4}{1}; & 4 < r \leq 5 \\ 0; & r \leq 1 \; or \; r > 5 \end{cases}$
$\mu_{HIGH}(r) = \begin{cases} \frac{r-3}{1}; & 3 < r \leq 4 \\ 1; & r > 4 \\ 0; & r \leq 3 \end{cases}$

The criteria are then chosen so that their combination gives a clear representation of the reaction by the users and the value they get from the virtual museum content. Weights for every criterion obtained from the individual weights are then combined to give the complete user profile. It aggregates interactions, preferences, and behavior of the user, whose weights are fuzzy, hence very implicit in terms of a profile for the user's interests.

- Aggregation: It combines fuzzy weights for the level of interest, engagement, and content relevance using weighted sum or any other aggregation method.
- Normalization: The method ensures consistency conservation by working out the combined weights on a standard scale for users and criteria.

From here, the fuzzy weights come up in the content management system of the virtual museum to exhibit presentations to be customized and recommendations to be offered.

- Exhibit and other Content Tagging: Tagged with metadata describing exhibits' features and potential areas of interest.
- Matching Algorithm: Fuzzy weights from user profiles are used to provide recommendations from user interest areas. This algorithm will dynamically update recommendations as the user will interact continuously.
- Dynamic Content Adaptation: In real-time, the CMS adapts content presentation by giving more emphasis on exhibits having higher fuzzy weight, and then it supplies supplementary information/multimedia regarding these exhibits.

The following decision rules (Table IV) combine the fuzzy values of IL, EN, and CR to determine the overall relevance of the content and guide the content adaptation process:

TABLE IV. DECISION-MAKING RULES

Rule	IL	EN	CR	Output	Content Adaptation
1	High	High	High	Highly Relevant	Show additional in-depth content.
2	High	Medium	High	Highly Relevant	Emphasize detailed content.
3	High	Low	Medium	Moderately Relevant	Show basic content with prompts for more engagement.
4	Medium	High	High	Highly Relevant	Show additional detailed content.
5	Medium	Medium	Medium	Moderately Relevant	Show standard content.
6	Low	High	Medium	Somewhat Relevant	Provide additional content to increase interest.
7	Low	Low	Low	Less Relevant	Show minimal content with suggestions

					for other exhibits.
8	Medium	Low	Low	Less Relevant	Show basic content with a prompt for rating.

Once the fuzzy weights for IL, EN, and CR are calculated and combined into a comprehensive user profile, these rules are used to dynamically adjust content presentation and recommendations.

IV. Evaluation Results and Discussion

To validate the effectiveness and potential of the VirtuMuse application, we conducted a rigorous evaluation process involving a diverse group of participants. The participants included 40 undergraduate 2nd-year university students interested in art and cultural heritage. Age and gender distributions were randomly selected and had no impact on the study's findings. The demographic analysis is shown in Table V.

TABLE V. Demographics

Measure	Item	Frequency	Percentage (%)
Sample size		40	100.0
Gender	Male	25	62.5
	Female	15	37.5
Age	18-19	28	70.0
	20-21	7	17.5
	Over 22	5	12.5
Level of Virtual Reality knowledge	None	5	12.5
	Medium	28	70.0
	Advanced	7	17.5

The evaluation process was designed to address the following key aspects:

- User Interaction: Assess the extent to which VirtuMuse promotes active engagement with the content and fosters a deeper appreciation and understanding of the featured exhibits.
- Personalization Accuracy: Determine the precision and relevance of the personalized recommendations generated by the fuzzy weights engine based on user preferences and interactions.
- Overall User Experience: Evaluate users' satisfaction with the features and user interface, and identify areas for improvement.

The authors interviewed the students to inform themselves about the application features using the full explanation of the design of the system as the framework of the conversation. Then, the guiding system and the plan were already assessed by the users, and recommendations for modification were sent to the authors. The recommendations deal with the system design and improving the whole tour process.

User Interaction:

- Question 1 (Q1): How often did you interact with the various features (e.g., zoom, click for more information) within the VirtuMuse application?
- Question 2 (Q2): To what extent did you find the interactive elements (such as virtual tours and interactive exhibits) engaging?

Personalization Accuracy:

- Question 3 (Q3): How well did the recommendations in VirtuMuse match your interests in art and cultural heritage?
- Question 4 (Q4): How accurately did the VirtuMuse application adapt content to your preferences based on your interactions?

Overall User Experience:

- Question 5 (Q5): How satisfied are you with the overall design and user interface of VirtuMuse?
- Question 6 (Q6): How easy was it to navigate through the VirtuMuse application?

A thorough examination of user input obtained from surveys and structured interviews was part of the VirtuMuse application review process. The surveys utilized a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) to assess participants' responses to specific questions related to user interaction, personalization accuracy, and overall user experience. The data were categorized into three groups: low (strongly disagree and disagree), fair (neither agree nor disagree), and high (agree and strongly agree).

Additionally, usage data such as the number of exhibits viewed, interactions performed (e.g., zooming, clicking for more information), and time spent on each exhibit were collected and analyzed. This quantitative data (Fig. 4 to Fig. 9) helped corroborate the survey findings by providing an objective measure of user engagement and interaction with the application.

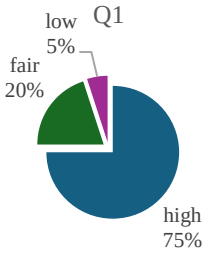

Fig. 4. Frequency of interaction with features.

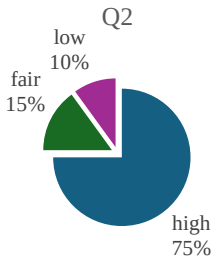

Fig. 5. Frequency of engagement.

The results indicate that the majority of participants frequently interacted with the various features of VirtuMuse and found the interactive elements highly engaging. Only a small percentage reported low interaction or engagement.

Participants generally felt that the recommendations provided by VirtuMuse closely matched their interests. The fuzzy weights engine effectively adapted content to user preferences, as reflected in the high ratings for both questions (Fig. 6 and Fig. 7) on personalization accuracy.

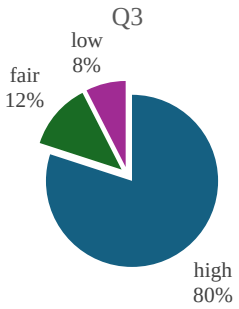

Fig. 6. Frequency of matching recommendations to interests.

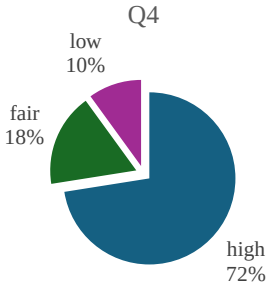

Fig. 7. Frequency of accuracy of content adaptation.

The majority of users were satisfied with the overall design and user interface of VirtuMuse, and found it easy to navigate. The high ratings in these areas (Fig. 8 and Fig. 9) suggest that the application is user-friendly and visually appealing.

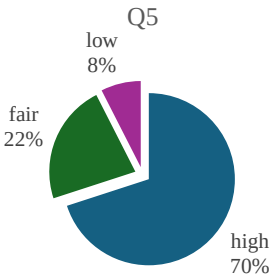

Fig. 8. Ssatisfaction with design and user interface.

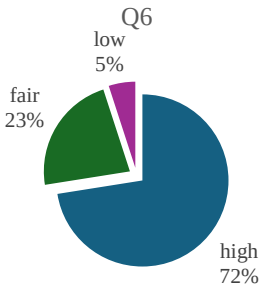

Fig. 9. Ease of navigation frequency.

Results from the evaluation of the VirtuMuse property are encouragingly positive towards an effective and engaging virtual museum platform. Among others, these include:

- High User Interaction and Engagement: Most participants interacted with different functionalities within the application rather frequently and found the interactive elements effective-this. A high interaction level has the potentials for VirtuMuse to have successfully carried out active engagement with content.
- Effective Personalization: The fuzzy weights engine used across VirtuMuse was seen to glean personalizable recommendations that made a good match for user interests. It made the participants feel the content was really adapted according to their preferences, which enhanced it further as an experience.
- Satisfaction and Ease of Use with System: VirtuMuse's design and functioning were appreciated by the users. It was an intuitive interface and ease of navigation that created such a hospitable user experience, convenient and enjoyable to use.
- Planet attitude to exhibits from the system logs: 99% of the exposes were marked with the "Like" feature; this testified to the overall general positive attitude the users had toward the content presented in VirtuMuse.

The VirtuMuse application generally makes itself invaluable in fostering appreciation and understanding of art and cultural heritage.

V. Conclusions

Evaluation of the VirtuMuse application has shown that it bears excellent potential to be an exciting and efficient application in art exploration using digital cultural heritage. The user response indicated high interaction ability with the characteristics of the application and especially welcomed its interactive functions together with suggestions for personalized content. Also, the positive response was increased by an easy-to-use interface and intuitive navigation once a high percentage of users declared to have been satisfied with the design and functionalities of the application.

Despite such very encouraging results, there are some limitations characteristic of this study-one, among them being its relatively small sample size, consisting of 40 undergraduate students that might not be duly representative of the broader population of probable VirtuMuse users. Also, the fact that only people interested in art and being university students participated in the study may have produced some bias. They were more willing to pay attention to such materials. The assessment was also done based on much self-reported data, which is pretty subjective and hence has not to model real users' behavior at any given time. Lastly, the current version of VirtuMuse might have a really meager content variety, which in turn, may bear on long-term user engagement and satisfaction.

Future work would thus have to be taken out to a more diverse and broad participant pool characterized by age groups, schooling backgrounds, interest in art, etc. Another developing the fuzzy weights engine with even more advanced algorithms and contents with interactive elements of the VirtuMuse would further facilitate continuation and higher levels of user engagement. Looking ahead in terms of the noted areas, VirtuMuse will continue to progress by organically growing its capacity to deliver an overall gradually personalized and engagingly immersive experience for its users on a larger scale.

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