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Exploratory Virtual Model: Study and Evaluation of a Low-Cost VR-Based Real Estate Sales Tool

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Abstract. Nowadays, it is common to find architectural scale models at real estate sales booths, as they are considered important sales tools. On the other hand, they are fragile, expensive, take considerable time to be made and have a short life span, as they are discarded when the sales booth is decommissioned. Full scale mock-ups share a similar context, but have even higher costs. In the search for alternatives, this paper studies the Exploratory Virtual Model (EVM), a system based on simple Virtual Reality techniques to be used at real estate sales booths which has the potential to eventually replace the architectural scale model or even the full-scale mock-up of apartments. The studied artefact can be implemented with simple VR tools and devices, namely: passive stereo projection and 6D-mouse. EVM may be implemented from the Building Information Model, saving even more development time and costs. EVM was evaluated through two case studies in real projects. In the first study, real estate brokers analysed it, while potential clients evaluated EVM at a sales booth in the second case study. Results show that EVM can be developed with much lower cost and shorter time than the architectural scale model or the full-scale mock-up apartment and that was well accepted and found useful by both real estate sales professionals and clients.

Key Words: real estate sales, virtual reality, BIM, stereoscopy
MSC 2020: 65U05

1 Introduction

A model is "a usually miniature representation of something" [20]. An architectural model is "a type of a scale model - a physical representation of a structure - built to study aspects of an architectural design or to communicate design ideas" [22].

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Scale models of buildings are present in most real estate sales booths. According to Campos [3], there are three requirements that justify the investment by the builders in the models: enchantment, clarification and information.

For Mills [11] the purpose of models is "to generate design ideas and serve as vehicles for refinement" and "investigation".

The sales booths are temporary constructions usually around the construction site of the future building, with the function of receiving potential clients to carry out commercial transactions.

Despite its effectiveness as a sales tool, the scale model presents important disadvantages: handmade product, fragile, high cost, considerable delivery time, short lifespan, limited viewing of the external areas of the project, large space occupied in sales booths, difficulty of faithful representation of the enterprise, shortage of qualified professionals (model makers) in the labor market, among others.

Additionally, in real estate sales booths, besides the architectural scale model, is also common to find apartment mock-ups. A mock-up is "a full-sized model of something [...] that is used for [...] showing its features" [21]. In this case, the mock-up is a 1:1 model of the actual apartment, visually identical to the final product, including furniture and other decoration items, but built with rapid production technologies and without fully working plumbing fixtures. The apartment mock-up is usually located on or near the sales booth, on the ground floor, and its purpose is to enable the potential customer to evaluate the interior and dimensions of the product for sale.

In contrast to the high costs of the mock-ups, IT resources have suffered a great reduction of price, while the performance of equipment grows exponentially [13].

In this context, we studied a "virtualization" of the mock-up i.e., replacing it with a computational device that provides the client an equivalent experience to the mock-up, without incurring in several of the disadvantages mentioned above.

In the search for alternatives without the shortcomings of the sales model, the Exploratory Virtual Model (EVM) was conceived. EVM is the presentation of the architectural design of the project, developed in Virtual Reality (VR), eventually based on a Building Information Model (BIM) of the building, and exposed by means of stereoscopic projection in the real estate sales booths.

With the introduction of EVM in the sales booth, the environment is more sophisticated and current, being a novelty for the customer because, besides replacing the scale model, an Information Technology device is added to it.

With the substitution of the scale model and the mock-up for digital electronic devices, other benefits are expected, such as reducing costs and shortening production times, as well as increasing the quality perceived by customers. One of the great advantages of the use of the geometric models in relation to the mock-ups is the representation in high level of detail, the simulation of materials and finishes, combining interactivity.

EVM can aid in the real estate sales because it provides resources such as navigation in internal and external environments that the scale model cannot reproduce, implying an experience with more subsidies for the purchase decision of the property. The possibility of visualization in natural scale of the interior of the building in high level of detail can eliminate the construction of the mock-up apartment too.

Although the theme of real estate sales supported by Virtual and Augmented Reality has recently gained more attention in research, the present work differs from previous works by not using fully immersive (e.g., VR glasses, CAVE, etc.) devices, focusing on inexpensive,

simple and less invasive equipment. This research main goal is to verify the effectiveness of this simpler apparatus for supporting real estate sales.

2 Literature Review

2.1 Building Information Modelling (BIM)

Sacks et al. [18] define BIM (Building Information Modeling) as "tools, processes and technologies [...] about a building, its performance, its planning, its construction and, later, its management. Therefore, BIM describes an activity, not an object". To describe the result of the modeling activity, the term Building Information Model is used. A Building Information Model: "is the digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onwards." [14].

The use of BIM has been growing worldwide [16], increasing the availability of architectural models for new buildings. Our proposal is that the EVM can be developed from the project building information model, as a byproduct of it, further reducing the production cost and ensuring design fidelity. Our estimate is that the availability of an architectural BIM model of a building can reduce the total cost of its EVM in about 58%.

2.2 Virtual Reality (VR)

Virtual Reality (VR) is "the use of computer technology to create the effect of an interactive three-dimensional world in which the objects have a sense of spatial presence" [19].

VR use in the field of Architecture, Engineering and Construction (AEC) is still low, but it has great potential [5], because AEC deals directly with the 3D space as VR does. Academia has been investigating uses for VR in AEC for more than a decade [4], including experiments with VR, Augmented Reality [9, 15] and Mixed Reality.

Lately, Building Information Models are being used as input to VR systems or VR is being used to visualize, interact and even to modify BIM models. Applications range from signage analysis [12] to construction site safety planning [7].

The investigation of the potential application of VR to real estate sales is increasing. In their studies, Azmi et al [1, 2] concluded that emotions induced in prospective house buyers by a VR environment could be the same they have when visiting the real physical space or a full-scale mock-up of it. Gunnarsson and Khan [8] concluded that presenting an environment to a potential buyer using VR "facilitates product knowledge and provides a hedonistic experience for the consumer.". However, this and previous research points that the use of VR does not necessarily induces more favourable product evaluations from potential buyers.

Like all the previous works, Deaky and Parv [6] also makes use of VR glasses in their experiment in VR for real estate application. Pleyers and Poncin [17] are an exception, in that they exam the use of a non-immersive VR technology for this application: interactive 360o panoramic views.

The application presented here also investigates a non-immersive VR technology for real estate sales, but a different one: polarized-stereo projection. It provides the user with depth perception but without the use of invasive, cumbersome and expensive accessories like VR-glasses / Head-Mounted Displays. Polarizing glasses can cost as little as $0.30 apiece.

3 Materials and Methods

The equipment used for this proposal is very common and low cost, differing from other works using often expensive VR glasses, for example.

3.1 Materials

The suggested infrastructure for the EVM is based on the minimum requirements for the execution of computer programs used to model the EVM and depends on the complexity of the model to be displayed:

- Microcomputer based on Intel® Core™ i5 Processor or equivalent, with 16GB RAM memory, video card with two video outputs;
- Two video projectors with linear polarizing filters; flat silver projection screen (which preserves the polarization of reflected light), measuring 72" × 96"; glasses with polarizing (linear) lenses;
- A six-degree-of-freedom input device for navigation on the virtual environment.

For the case studies, a system with two video projectors with 1280 × 800 resolution, 4000 lumens and linear polarizing filters and five plastic-frame linear polarizing glasses was adopted. The 3Dconnexion SpaceNavigator was chosen as the navigation input device and a NVIDIA GeForce GTX 460 as the video card.

In the development of the EVM, Graphisoft Archicad was used for creating BIM models which were later interactively navigated using the free BIMx viewer. This approach is cheaper, faster and more straightforward than most solutions which usually adopt VR environments based on game engines (e.g., Unreal, Unity, etc.) as the BIM model can be directly navigated without the need for customized format conversions.

Statistical analyzes were carried out in SPSS (Statistical Package for the Social Sciences).

For the evaluation interviews, a questionnaire with answers using a Likert scale was developed. This scale was adopted because it is objective, easy to understand and fast to complete, since the developers requested that the answer time demanded from their employees and clients in the evaluation should not exceed five minutes.

3.2 Method

The main activities that constitute the method developed in this research were:

- Bibliographic research on the themes: Mock-ups, BIM and Virtual Reality;
- Proposition of requirements for a system that implements the Exploratory Virtual Model concept;
- Search for commercial products that meet EVM specifications;
- Two case studies involving real projects were developed to evaluate:
  - The use of EVM by primary users (real estate brokers);
  - The use of EVM by secondary users (clients);
- Perform a cost and time comparison of the traditional vs the EVM approach.

The following steps were performed:

- Selection, for conducting the case studies, of residential building projects at the sales phase that had a physical model and, preferably, a mock-up apartment on display. For the evaluation of the EVM by the clients, the installation of the EVM in the sales booth was required;

- Development of EVM for the case studies, involving modelling of the buildings (including common and interior areas) and assembly of the physical infrastructure for presentation;
- Development of questionnaires to be applied to real estate brokers and clients, with preliminary validation;
- Application of questionnaires to brokers and clients after their practical experimentation with EVMs;
- Statistical analyses of the data collected. The statistical analyses involved the descriptive characterization of the data and the verification of the existence of associations between the demographic data of the respondents and their answers to the questionnaire, as listed below:
  - Descriptive analyses of frequency, mean, median, mode, mean deviation, standard deviation, maximum and minimum values and percentiles of variables;
  - Checking the normality of the variables through the Kolmogorov-Smirnov test to define which statistical tool to apply;
  - Significant associations between the questionnaire responses and the demographic variables were observed (Gender, Age and Education). It was used the ANOVA (if normal variable) or the Mann-Whitney test (if there is no adhesion to the normal distribution).
  - Frequency comparison of answers for each question of the questionnaire, for qualitative evaluation of EVM.
- Solutions cost and time comparison:
  - Determination of estimated costs and time to produce of scale models and full-scale mock-ups for the case studies;
  - Determination of estimated costs and time for commercial production of EVM models and for the associated infrastructure needed for presentation at the sales booth.

4 Results

After careful identification of available building projects on the sales phase in the city of São Paulo and whose owners were willing to participate in this research, two suitable projects were identified to be the object of the case studies.

4.1 4.1 Case Study 1: EVM for Real Estate Brokers Evaluation

The implementation of the EVM for the case study 1 included the real estate sales team of a large Brazilian real estate developer. The chosen project was Villaggio Luna Residencial (Figure 1).

This is a single tower, U-shaped floorplan project, with nine floors, 209 three-bedroom residential apartments, ranging from 110 to 155 square metres each. The EVM modelled for case study 1 can be seen in Figures 2 to 4:

4.2 Case Study 2: EVM for Client Evaluation

The implementation of the EVM for the case study 2 occurred for clients and visitors of the sales booth of another large national real estate developer. Their chosen project for

Figure 1: Villaggio Luna Residencial (rendering and façade photo). Source: Cyrela Brazil Realty

Figure 2: Front and rear façades from the EVM modelled.

participating in this research was the Le Klabin building (Figure 5). This building was chosen because it had a sales booth with the environment prepared for the so-called "3D Cinema", where they showed a walk-through animation video of the project, rendered in stereo 3D. Their setup was similar to the one used in case study 1, but lacking a navigation device as the animation was pre-rendered. The researchers augmented it with the SpaceNavigator and replaced the video player with the BIMx interactive viewer and our BIM model.

This is an upscale 21-floor single tower building with 268-square-metre apartments, 3 to 4 bedrooms each. Figures 6 and 7 show images of the EVM developed for this project.

4.3 Questionnaires

Both questionnaires (for brokers and for clients) used the following Likert scale for the responses: Completely disagree (CD); Partially disagree (PD); Indifferent (I); Partially agree (PA); Completely agree (CA);

Initially, a questionnaire was tested with seven brokers who were shown a partial EVM.

Figure 3: Leisure area and balcony from the EVM modelled.

Figure 4: Interiors (living room and kitchen) from the EVM modelled.

Figure 5: Le Klabin building (rendering and façade photo). Source: Queiroz Galvão Desenvolvimento Imobiliário

The results of this test served to refine the questionnaire by reducing the number of questions and improving the writing and overall graphic appearance, among other improvements. At that point, we wanted to anchor the final decision on the issues, understanding what possible answers could be obtained and what information was really needed.

In the case studies, prior to the application of the questionnaires, both brokers and clients received a brief explanation of the experience, followed by a navigation in all the environments of the respective case studies by a researcher. Following that, they were requested to navigate the virtual model by themselves.

The questionnaire was based on five essential guidelines for the survey: satisfaction, recognition, understanding, navigation and purchase decision, because the purpose of the questionnaire was to evaluate the efficiency of the tool in the purchase decision. It was divided in two parts:

- In the first part of the questionnaire, demographic information of the respondent was

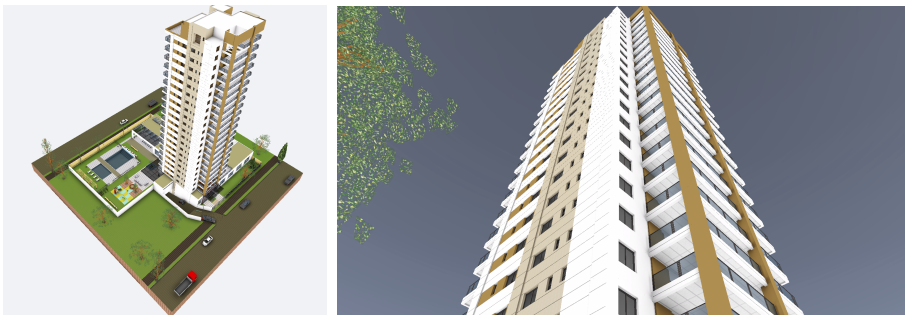


Figure 6: Full site and façade from the EVM modelled.

Figure 7: Interior and leisure area from the EVM modelled.

Table 1: Demographic characterization of brokers

Characteristics	n	%
Gender		
Female	34	55.7
Male	27	44.3
Education		
High School	04	6.6
Incomplete Higher Education	08	13.1
Complete Higher Education	39	63.9
Post-Graduation	10	16.4
	Average (DP)	**Median (P25–P75)**
Age (years)	37.15 (10.15)	34 (30–44)

obtained;

- In the second part, the respondent's views on the EVM were requested.

4.4 Data Collected from Respondents

The EVM evaluation by brokers was carried out in their company's headquarters, with 61 brokers. The majority were female, with a mean age of 37.15 (SD = 10.15, min = 20 and max = 65) and higher education (Table 1).

The Table 2 shows the data for the evaluation of EVM by brokers.

The EVM evaluation by the clients, through the application of a questionnaire, was carried out at the sales booth of the project, for 16 clients and visitors. The majority were female, with a mean age of 44.75 (S = 10.13, min = 19 and max = 58) and complete higher education (Table 3). A summary of the collected data is shown on Table 4.

4.5 Estimation of Cost and Time

For the case study 1, we collected data from the project managers. The cost of the scale model of the study case 1 building was equivalent to about US$9,100.00 and took 45 days to complete. The full-scale mock-up cost the equivalent to US$149,350.00 at the time this research was conducted, and was built in 35 days. On the other hand, the estimated retail cost of the EVM for case study 1 was US$9,956.00 and it demanded 6 days of work to

Table 2: Broker's response data (case study 1)

Question	CD		PD		I		PA		CA	
	n	%	n	%	n	%	n	%	n	%
a) I was pleased with the virtual visit to the project using the EVM.	—	—	—	—	1	1.6	18	29.5	42	68.9
b) EVM complements the scale model (SM) by means of the virtual visualization of the interior of the environments.	—	—	—	—	2	3.3	17	27.9	42	68.9
c) EVM complements the SM by visualizing the external area of the project.	—	—	1	1.6	1	1.6	10	16.4	49	80.3
d) EVM replaces the SM.	23	37.7	16	26.2	4	6.6	14	23.0	4	6.6
e) I visited, without getting lost, the internal environments of the enterprise while I was moving through the EVM.	—	—	8	13.1	5	8.2	23	37.7	25	41.0
f) I visited, without getting lost, the external area of the enterprise while I was moving through the EVM.	—	—	4	6.6	4	6.6	20	32.8	33	54.1
g) Through EVM, I realized how the dimensions of each environment of the project are.	1	1.6	4	6.6	1	1.6	20	32.8	35	57.4
h) I understood how the internal environments of the apartments are distributed in EVM.	—	—	3	4.9	—	—	18	29.5	40	65.6
i) I understood how the external area of the project is distributed in the EVM.	—	—	—	—	—	—	14	23.0	47	77.0
j) I walked with ease through the internal environments of the enterprise in EVM.	—	—	1	1.6	2	3.3	23	37.7	35	57.4
k) I walked with ease through the external environments of the enterprise in EVM.	—	—	1	1.6	2	3.3	15	24.6	43	70.5
l) I would like to have available and I would use the EVM if lacking a full-scale apartment mock-up.	2	3.3	—	—	1	1.6	13	21.3	45	73.8
m) I would use the EVM in addition to the full-scale mock-up.	3	4.9	1	1.6	—	—	9	14.8	48	78.7
n) EVM replaces the full-scale apartment mock-up.	27	44.3	14	23.0	2	3.3	14	23.0	4	6.6
o) I consider the EVM a useful sales tool for the residential real estate market.	—	—	—	—	1	1.6	11	18.0	49	80.3
p) I find it useful to have more than one EVM of the project at the sales booth.	1	1.6	2	3.3	5	8.2	13	21.3	40	65.6

CD = Completely disagree; PD = Partially disagree; I = Indifferent; PA = Partially agree; CA = Completely agree

complete [10].

Table 3: Demographic Characterization of Clients

Characteristics	n	%
Gender		
Female	9	56.3
Male	7	43.8
Education		
High School	1	6.3
Incomplete Higher Education	3	18.8
Complete Higher Education	10	62.5
Post-Graduation	2	12.5
	Average (DP)	**Median (P25–P75)**
Age (years)	44.75 (10.13)	46 (43–48)

For the case study 2, we were unable to obtain actual costs for the displayed (1:40) scale model. For estimating its cost, quotations were obtained from five service suppliers for an equivalent scale model, resulting in an average cost of about US$12,000.00 and 39 days for delivering the completed model. BIM modelling time for this building was 49.5h, equivalent to 6.2 days – therefore, the EVM estimated cost was similar to that of the study case 1 EVM [10].

5 Results Analysis

Association analyses between the questions and the demographic data of the brokers and clients (gender, age, knowledge of the enterprise and training) were carried out. And, by means of the variance analysis (ANOVA), whose test compares the distance between the sample means and the variation within the samples, it can be seen the absence of a statistically significant association ($p < 0.05$).

In the data analyses, the response categories were recoded for “Disagree”, “Indifferent” and “Agree” because of the low frequency in each of the five original categories. With the recoded answers, new spreadsheets were compiled that formed the data for the composition of the charts.

Therefore, in light of the collected data, demonstrated in the graphs, it is possible to infer the acceptance of the virtual model by the brokers.

5.1 Case Study 1

Brokers were satisfied with the virtual experimentation in the EVM (Figure 8).

Although most brokers think that EVM does not replace the scale model or the full-scale apartment mock-up, they conclude that the EVM complements them and would use it in lack of mock-up. Also, results in Figure 8 (right) show that almost all brokers (98.36%) agree that EVM is useful for the Residential Real Estate Market.

Regarding the estimated costs and time, EVM cost about as much as the scale model, but was 15 times cheaper than the full-scale mock-up. The time to produce the EVM was less than 1/6th of the time it took for building either the scale or mock-up models.

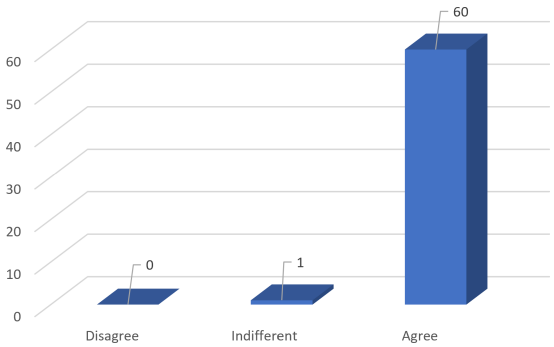
Table 4: Client's response data (case study 2)

Question	CD		PD		I		PA		CA	
	n	%	n	%	n	%	n	%	n	%
a) I was pleased with the virtual visit to the project using the EVM.	—	—	—	—	—	—	4	25.0	12	75.0
b) EVM complements the scale model (SM) by means of the virtual visualization of the interior of the environments.	1	6.3	—	—	—	—	2	12.5	13	81.3
c) EVM complements the SM by visualizing the external area of the project.	3	18.8	—	—	—	—	2	12.5	11	68.8
d) EVM replaces the SM.	4	25.0	1	6.3	1	6.3	1	6.3	9	56.3
e) I visited, without getting lost, the internal environments of the enterprise while I was moving through the EVM.	1	6.3	1	6.3	1	6.3	4	25.0	9	56.3
f) I visited, without getting lost, the external area of the enterprise while I was moving through the EVM.	—	—	1	6.3	1	6.3	2	12.5	12	75.0
g) Through EVM I realized how the dimensions of each environment of the enterprise are.	1	6.3	1	6.3	1	6.3	3	18.8	10	62.5
h) I understood how the internal environments of the project are distributed in EVM.	1	6.3	—	—	1	6.3	1	6.3	13	81.3
i) I understood how the external area of the project is distributed in the EVM.	—	—	1	6.3	—	—	3	18.8	12	75.0
j) I walked with ease through the internal environments of the enterprise in EVM.	—	—	3	18.8	1	6.3	3	18.8	9	56.3
k) I walked with ease through the external environments of the enterprise in EVM.	—	—	2	12.5	1	6.3	2	12.5	11	68.8
l) I would like to have available and I would use the EVM in the absence of a full—scale apartment mock—up.	—	—	1	6.3	1	6.3	3	18.8	11	68.8
m) I would use the EVM in addition to the decorated apartment mock-up.	2	12.5	1	6.3	—	—	1	6.3	12	75.0
n) EVM replaces the full-scale apartment mock-up.	5	31.3	3	18.8	—	—	3	18.8	5	31.3
o) The use of EVM helped me to decide whether or not to buy the property.	2	12.5	—	—	4	25.0	2	12.5	8	50.0

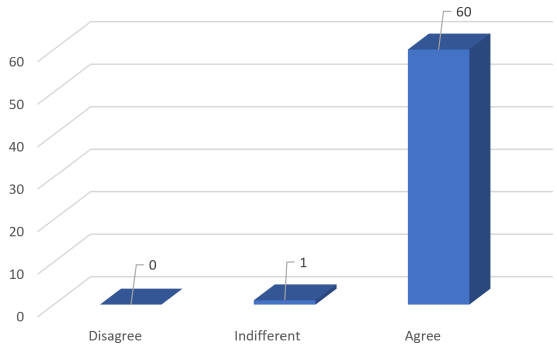
CD = Completely disagree; PD = Partially disagree; I = Indifferent; PA = Partially agree; CA = Completely agree

5.2 Case Study 2

In the same way, Figure 9 shows the acceptance and satisfaction with the virtual model by real estate clients but, like in case 1, it cannot be said that the EVM replaces the scale model

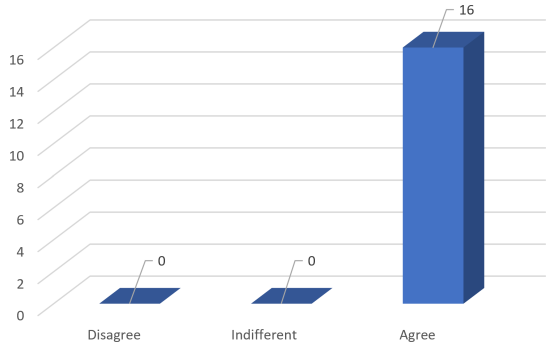


Satisfied with the virtual visit

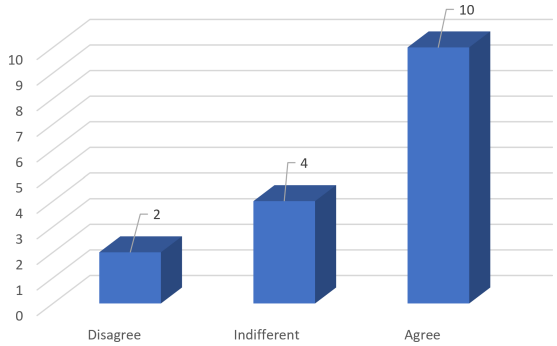


EVM is useful for the residential real estate market

Figure 8: Brokers' view on the EVM



Satisfied with the virtual visit



EVM is useful for decision to purchase the property

Figure 9: Clients' view on the EVM

of the apartment mock-up in their opinion.

Figure 9 (right) illustrates that the majority of clients (62.50%) agree that EVM would help them in the decision to purchase or not the property.

The time it took for producing the study case 2 EVM compared to its physical counterpart was similar to the one in study case 1 (one-sixth) and the cost was even lower – about 83% of the scale model estimated price.

6 Conclusions

With the research, we could study in detail products (equipment and computer programs) and services that, when integrated, formed a low-cost VR sales tool, the EVM.

EVM has proved suitable as a real estate sales tool in sales booths of residential buildings, because:

- It can be effectively navigated both by sales professionals and clients;
- It can show the interior and exterior areas of real estate projects with virtual tours that simulate the real tours;
- It can developed with low investments in equipment and computer programs;
- It allows the virtual visualization of different projects (several EVMs) in the same sales booth.
- It has lower cost and production time compared to scale models and full scale mock-ups.

In addition, the EVM proved to be complementary to the scale model and mock-up apartment, introducing a new concept of exhibition of real estate projects. It is worth noting that in sales

booths that do not have the scale model or the full-scale mock-up, whether due to lack of space or financial reasons, EVM can replace them effectively, since it demonstrates in detail the real estate property.

With case studies 1 and 2, the efficiency of EVM was validated through the opinion of real estate sales professionals and real clients as a sales tool for professionals and as a product evaluation tool for the purchase decision by clients, respectively.

The EVM can be obtained directly from a BIM model of the project, further reducing its production cost with the guarantee of fidelity of the virtual model to the original design.

Therefore, it is concluded that EVM is a valid tool that fulfils its intended purpose: to establish itself as a sales tool for the residential real estate market.

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