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# ADAPTATIVE VISUALISATION SYSTEM FOR CONSTRUCTION BUILDING INFORMATION MODELS USING SALIENCY

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**ABSTRACT:** Building Information Modeling (BIM) is a recent construction process based on a 3D model, containing every component related to the building achievement. Architects, structure engineers, method engineers, and others departments to the building process work in collaboration on this model through the design-to-construction cycle. The high complexity and the large amount of information driven by novelization in the model raise several issues and delaying its wide adoption in the industrial world. One of the most important is the visualization: professionals have difficulties to find out the relevant information for their job. Actual solutions suffer from two limitations: the BIM models information are processed manually and insignificant information are simply hidden, leading to inconsistencies in the building model. This paper describes a system relying on an ontological representation of the building information to label automatically the building elements. Depending on the user's department, the visualization is modified according to these labels by automatically adjusting the colors and image properties based on a saliency model. The proposed saliency model incorporates several adaptations to fit the specificities of architectural images.

**KEYWORDS:** Saliency, Building Information Modeling, Virtual Reality, Building Architecture, Data Visualization, Immersion, Knowledge Representation, PSwarm.

## 1. INTRODUCTION

In architecture, the construction process underwent a major shift in the past 5 years with the increasing adoption of Building Information Modeling process (BIM) to design and achieve all kind of structures. These processes are based on a 3D model containing the information required to achieve the building. The model could be used to supervise the construction project in term of design and architecture with lightings simulation or rendering pictures, but it mostly used in a technical approach (Ernstrom, 2006; Innovation, 2007; Kymmell, 2008). Several distinct experts contribute to BIM models. Each one modifying or adding its own objects and notes on the 3D model. As shown in Figure 1, this 3D model gathered all the information coming from different user profiles (architect, method, structure ...).

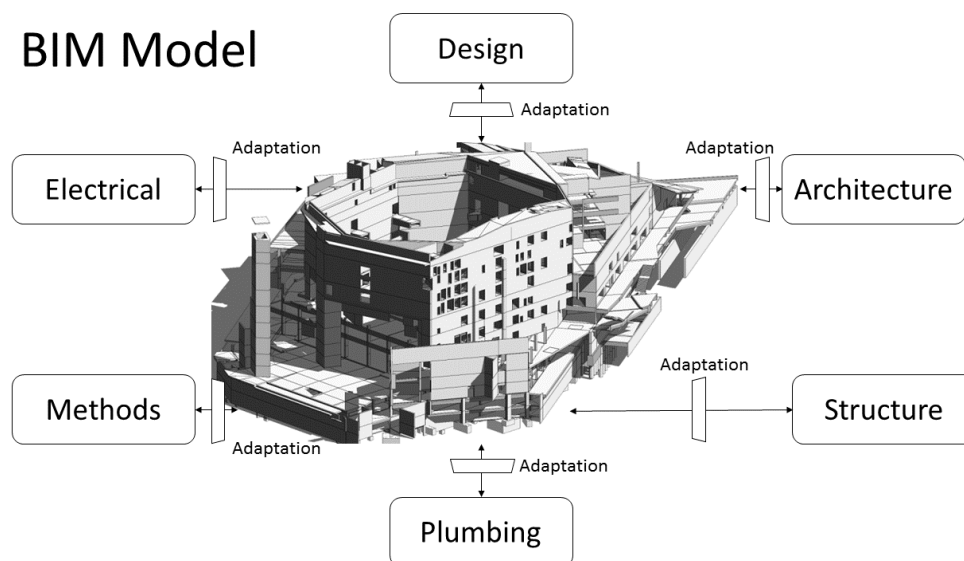


Figure 1: Sketch of BIM process. All professions work on the same model but need different information.

Nowadays, BIM process is not completely integrated in building's design. Most of the BIM models are uncompleted and contained elements are not clearly classified. All user profiles do not require all information from the model; e.g. the position of electric cables is mostly irrelevant for a structure engineer, but it is needed at some point to check interactions between electric cables and structures. To improve the efficiency and quality of the BIM work, it is important to adapt the visibility of each object depending of the user's profile. The actual industrial process is to manually hide with a transparency effect all the irrelevant objects for the user. An architect would hide construction elements like crane or scaffolds. This method is the cause of major problems, as the manual operations are known to be error-prone and time consuming. Also completely hiding objects often lead to clashes between elements, for example a cable going through a water pipe, which is a common issue in BIM processes.

This paper proposes an assistive system for construction engineers and BIM users. This system uses an ontology to represent the building information and enhance the visualization of 3D models. It classifies automatically BIM components in real time and adapts their colors regarding the user's interest. Our system proposes visualization method where the most important components capture the visual attention while maintaining all components on screen.

An eye tracking device could be used to accurately capture the gaze of the user during their interaction with the system. However, this approach suffers from two limitations. Firstly, the design and parametrization of a system based on eye-tracking recordings is a time-consuming process. It implicates that building experts spend a lot of time calibrating the system. Thus the effective cost will be very high. Secondly, with eye-tracking device it is not possible to produce an online system, which automatically adapts the visualization depending on the properties of the visual scene. For example, under a certain point of view, an object could require an enhancement to be salient, while it could already be salient when looking at it from another point of view.

Saliency models are mostly used for image analysis and capturing the focus of human perception. In the work, we make use of saliency model for image synthesis and we exploit the efficiency of these models to propose an assist system. The visualization of the 3D is thus modified to enforce the saliency of the relevant objects for a specific user profile.

Most of the saliency models are assessed on natural images (such as landscaped, portraits...). The architectural images generated by 3D building models display some recurring properties and different from natural images. The most visible property is the strong presence of vanishing points and the second one is the importance of depth in those images. We proposed specific adaptations of the saliency models to suit those properties of architectural images. This work will then be integrated in an industrial BIM viewer for Bouygues Construction and applied on the design of real projects.

Thus, the contribution of our system could be summarized as:

- Ontology of building information models: from the knowledge of BIM managers, we propose an ontology and a classification of BIM elements depending of their interest for each profession department.
- Adaptation of the saliency model to architectural images: Notable saliency systems are mostly based on 2D images. BIM and architectural images present particularities that we take into account.
- Online and real-time visualization system: We propose a system which modify colors depending of the user profession. The system works in real time and is integrated in a BIM viewer to assist users.

This paper is organized as Follows. Section 2 describes the state of the art on building management ontology and defines our goals for the system. The application of saliency methods are also justified and the specificities or architectural images are pointed out. Section 3 introduces our model and explain our contributions. Section 4 details the experiments and in Section 5 a discussion about benefits of the proposed system is described.

## **2. STATE OF THE ART**

### **2.1 Building Management Ontology**

Two different approaches could be identifiable in the literature on ontology applied to building management. The first approach is task-centric and aims at assessing the benefit of BIM versus non-BIM technologies, relying on a complete description of the tasks taking place in the building design process (Li et al., 2014). The work developed in this paper follows a second approach, user profile-centric: all 3D model objects are classified depending on their relation with the user's profile. This classification is either based on the intrinsic properties of the object (Aksamija and Grobler, 2007) or from a model of interaction between different actors (Costa and Lima,

2014; Lee et al., 2014). As such, an element of the 3D model, for example a wall, is relevant for the work of a structure engineer, but is not for a plumbing engineer who is concerned by pipes and water circulation.

## 2.2 Saliency

Saliency models are computer vision tools to automatically detect visual attractive parts of an image. It is based on the analysis of colors and orientation's contrasts. The result detect the relevant elements of the image. Many computational models have been proposed to predict the visual attention through saliency map, such as (Huang and Ahuja, 2012; Itti and Koch, 2000; Tsotsos et al., 1995). A comprehensive review could be found in (Zhao and Koch, 2013) and an assessment of the existing models is proposed on the MIT saliency benchmark (Bylinskii et al., n.d.). A commonly used methodology in saliency-based models is to analyze the contrast of an image in term of intensity, color and orientation. Saliency models are an easy and fast way of analyzing images and predicting an accurate map of visual attention. Hence saliency models could analyze an image coming from a BIM scene and determine the visually attractive elements of the scene.

In the context of architectural images, the visual scene often display strong depth information and vanishing point. It has been shown that the depth clues are highly informative and have a strong influence on object saliency (He and Nakayama, 1995; Lang et al., 2012). Several works linking vanishing point and visual attention have been conducted. (Stentiford, 2006) has proposed to detect vanishing points based on the visual attention. (Itti and Koch, 2000) model integrated the orientation analysis following constant axes (vertical, horizontal and diagonal). Architecture pictures contain important vanishing points which are easily detectable (Rother, 2002; Van Den Heuvel, 1998) as most of the shapes following the projection of vanishing points. If an object does not contribute to the global perspective, its visual saliency is increased.

## 3. ONTOLOGY-BASED VISUALIZATION SYSTEM

### 3.1 Description of the Proposed System

The majority of the saliency models are developed using standard 2D pictures. These models consider orientations in flat images, the visual saliency is computed for all constant angles. Our system implement a method that detects vanishing points and compute orientation map from a projection of these points (described in Sect 3.2). In BIM case, all images are generated by a 3D viewer software with engineer colors only chosen to make a contrast between elements. The employed color codes do not contain major information; often colors are chosen randomly. We used saliency model for image synthesis, guiding the color choice to maximize the saliency of important BIM components in the scene. Combined to a color selection algorithm, our system selects colors which keep the visual attention of the user on important elements without hiding or deleting other. Our algorithm is described in Sect3.3.

### 3.2 Vanishing Point-Sensitive Computation

This paper proposes a method to take into account vanishing point in saliency model. The orientation detection was replaced by a vanishing point projection process. Our system relied on the work of Feng for the detection of the vanishing points (Feng et al., 2010; Tardif, 2009). As an illustration, we applied our algorithm on a sample image and the result is shown Figure 2. From an input image, the vanishing point are detected with the Feng algorithm, the projection from this vanishing point is computed. The projection image is tend analyzed in its vertical contrast. An inverse transform of the result is added to the global model as the orientation conspicuity map, as shown on the right part of Figure 3. This figure displays the saliencies computed with the original Itti model on the left and the saliencies obtained with our model on the right.

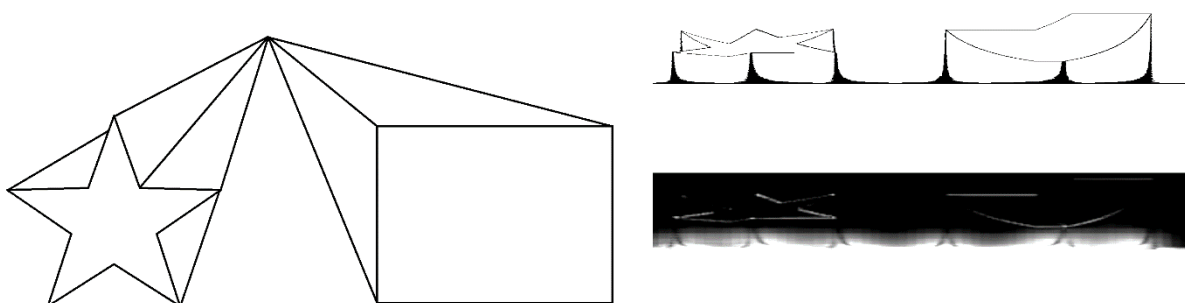


Figure 2 : Left: original image with obvious vanishing point. Top right: result image after vanishing point projection. Bottom right: the vertical orientation map.

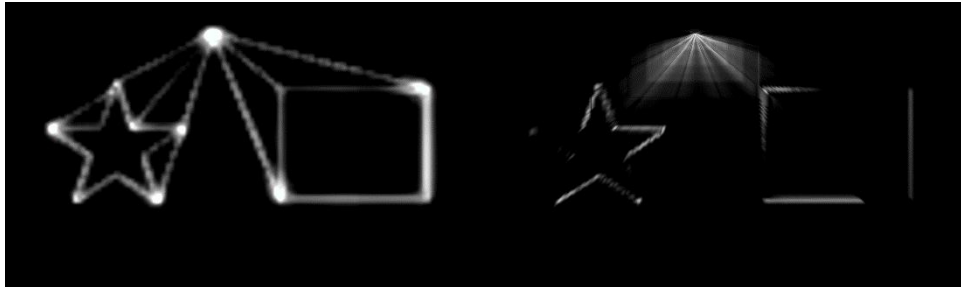


Figure 3: Left: orientation conspicuity map computed from 0, 45, 90, 135 orientations, as in (Itti et al., 2000). Right: orientation conspicuity map computed with our model. Edges that do not contribute to the perceptivity are stood out.

The saliency model of the proposed system takes also into account the contrast of depth. The 3D software computes a depth map associated with each generated image. We have implemented the work of (Jost et al., 2004) to include the information extracted from a depth conspicuity map in the system. In the proposed saliency model, other features map are computed as in the Itti model (Itti and Koch, 2000). Thus four conspicuity maps are built: the perspective orientation map, the intensity map, the color map and the depth map, are then combined in the saliency map shown on Figure 4.

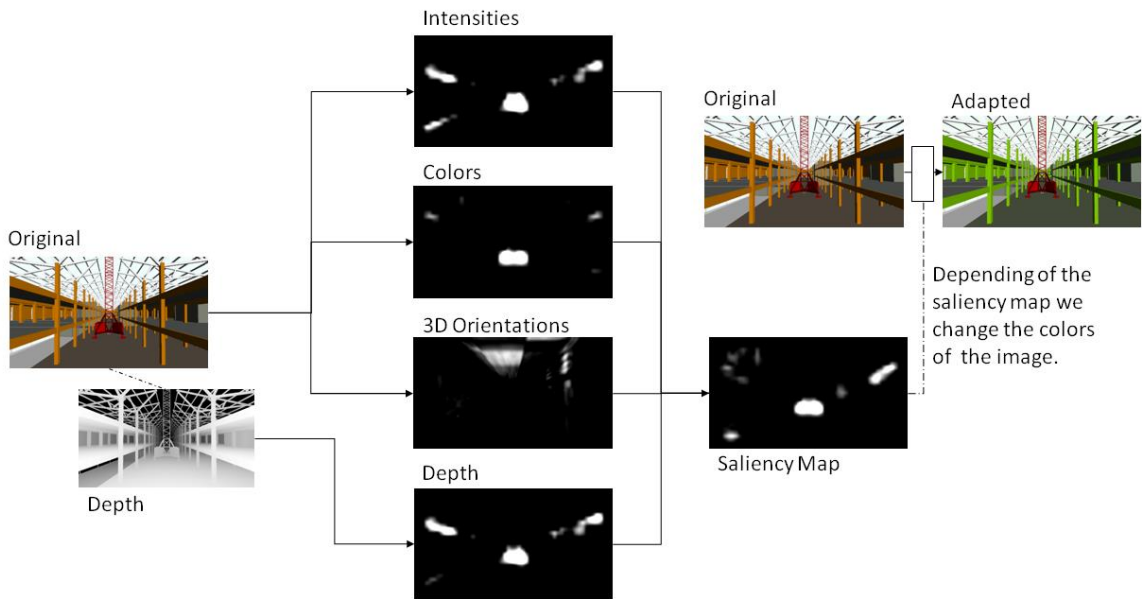


Figure 4: Architecture of the saliency model: conspicuity maps of intensity, colors and 3D orientations are extracted from the 3D snapshot. Depth conspicuity map is computed from depth information of the model. The saliency map combines all the conspicuity maps. Salient locations are used to adapt the color scheme of the original image to enhance object relevant to the user profile.

### 3.3 Enhancing Visual Attention

The proposed system implements an online adaptation of the image visualization. The aim is to choose colors that emphasize the visual saliency of the relevant elements. The works of (Healey and Enns, 2012; Ware, 2004) describe links between visual attention, visualization and colors. The through experiments of (Wolfe, 2000) characterize the links between colors and visual attention. Colors of BIM model do not convey information. There are chosen semi-randomly only to create a different between several elements. In the proposed approach, most of the adaptation of the original image is done on the color channels, as it is a lossless transformation regarding the BIM model. It should be noted that as BIM models become more complex and include more elements, the probability of finding two different objects with a similar color drastically increase, thus production incomprehensible visualization of IBM models. Our system does not alter the user-defined colors, but could modify the color of any element label as unimportant with respect to the user profile.

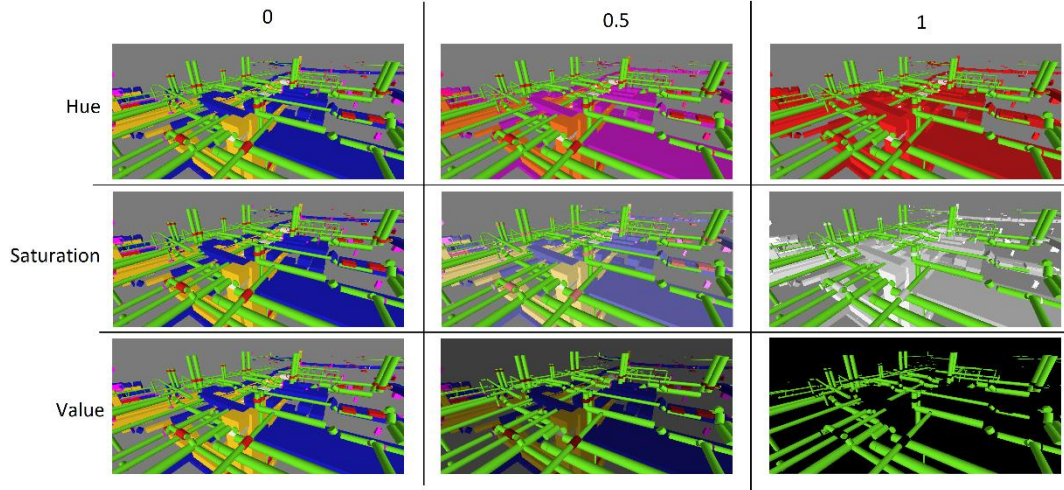


Figure 5: for each row, representation of modification of each parameter (hue, saturation, value). Each column defines 3 different values for the parameters: 0, 0.5 and 1. For the hue parameter (1<sup>st</sup> row), irrelevant elements turn proportionally to red which is the opposite color of green. The saturation parameter (2<sup>nd</sup> row) detect that the relevant elements are composed of mostly saturated green color, thus irrelevant element turn unsaturated. Value parameter (3<sup>rd</sup> row) detect a bright color for relevant color then turn dark irrelevant region. For a 0 parameter (1<sup>st</sup> column) the originals colors are kept.

To redirect the visual attention on the relevant objects, the aim of the system is to modify in term of hue, saturation and the value of the irrelevant pixels. As shown on the Figure 5, our system has the capacity to proportionally and independently change the three parameters  $P \in [0,1]^3$  of irrelevant pixels. The saturation and the value are simply decreased while the hue follows a more advanced behavior. Depending on the average element color, a target color  $T$  is defined (see Table 1). This target color is the opposite of the relevant region's pixel color. As main idea is to reinforce the color contrast of the image depending on the relevant image elements.

Table 1 : In hue value  $[0^\circ, 360^\circ]$ , the average relevant color on the right and the targeted value to enhance contrast of colors.

Average Color ( $^\circ$ )	Target ( $^\circ$ ) = $T_l$
$[0, 30[$	$120^\circ$
$[30, 90[$	$240^\circ$
$[90, 120[$	$0^\circ$
$[120, 240[$	$60^\circ$
$[120, 360]$	$120^\circ$

The aim of this paper is to enhance the global saliency of an object keeping a maximum of the global colors of the scene, which means to keep irrelevant elements the maximum perceptible without being salient. The system

thus need two indexes to control these two information. To get the visual attention ratio of the relevant the saliencies are computed from a screenshot provided by the 3D real time viewer. From the obtained saliency map, regions belonging to relevant and irrelevant elements are tagged as such  $R = \{p_a\}_{a \in A}$  and  $I = \{p_b\}_{b \in B}$  are respectively the set of relevant and irrelevant regions in the image, where  $A$  and  $B$  are the indexed set of pixel  $p_a$  and  $p_b$  belonging to relevant and irrelevant objects. Sky and ground's pixel are considered belonging to irrelevant region  $I$ . The complete image  $J$  is thus described as such  $J = \{R \cup I\}$ . From our adapted saliency model, the average saliency  $S_R$  and  $S_I$  of  $R$  and  $I$  regions is computed. Then the ratio  $G_e$  which represents the saliency proportion of the relevant region  $R$  versus the global saliency following

$$G_e = \frac{S_r}{S_r + S_i} \in \mathbb{R}_+$$

At the same time, the global color distance of an irrelevant object is computed to evaluate the observability of the different elements composing the irrelevant region  $I$ . The irrelevant regions could contained several type of elements. For example, if the user's relevant elements are plumbing, structure and electrical elements are irrelevant while being severable.  $I_x$  represents the irrelevant region  $I$  of the irrelevant element  $x$ . The resulting distance is computed from the Hausdorff's distance between each elements colors. Formally, it is:

$$d_H(I_x, I_y) = \max\{\sup_{i_x \in I_x} \delta(i_x, I_y), \sup_{i_y \in I_y} \delta(i_y, I_x)\}$$

where  $\delta(a, B) = \inf\{\delta(a, b); b \in B\}$  is the distance from the pixel  $a$  to the region  $B$ . We get then the color distance between every  $n$  irrelevant objet. The system then considers the minimum distance  $\hat{C}$  such as:

$$\hat{C} = \min\{d_H(i, j)_{\forall i, j \in n, i \neq j}\} \in \mathbb{R}_+$$

The system use the particle swarm pattern search method (Vaz and Vicente, 2009). The principles of this optimization is to generate particle to find the optimum solution of a problem. Each particle represents a proposition of a trio of parameters. From an optimization function  $(G_e, \hat{C}) = f(P)$ , find the particles  $P_k = (p_h, p_s, p_v)$ ,  $k = 1, 2, \dots, K$  particles (size of the PSwarm). Depending of the result, particles are moving to obtain the minimum value following:

$$[P_h, P_s, P_v] = \min \left\{ \frac{1}{G_e^t} + \frac{1}{\hat{C}^{1/t}} \right\}$$

where variable  $t$  is the parameter which decides to protect either the visual attraction (maximizing  $G_e$ ) or protect the color of the irrelevant elements (maximizing  $\hat{C}$ ). The resulting image could be found in Figure 6, where the relevant elements are stood out keeping a maximum of other information for the irrelevant regions.

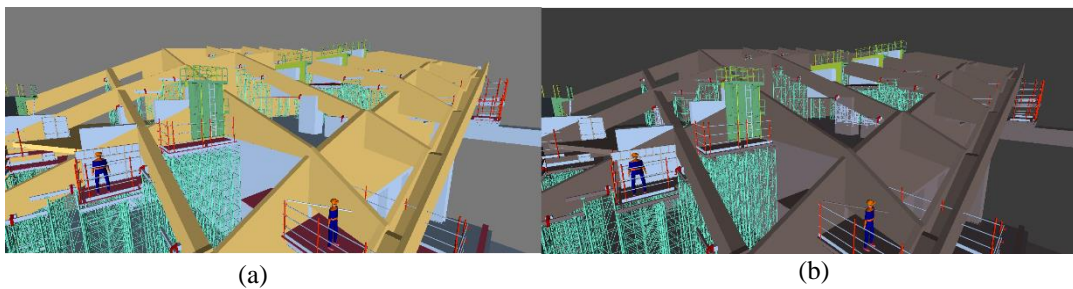


Figure 6: Example of an image of the experiment. Experts are asked to answer the following question: “Considering that you are mostly interested by your profession’s elements. In your opinion, which picture seems the more visually pleasant?” Five choices are allowed for the experts: “left”, “probably left”, “indifferent”, “probably right” or “right”. The left image is the original one; on the right one, the colors are enhanced by our saliency processing. Only the color coded information are changed to emphasize the method objects (scaffolds and worker) The gray and yellow elements from original image (left) are changed to reddish in the saliency-enhanced image (right). The global saturation and luminance are slightly decreased (right).

## 4. EXPERIMENTAL VALIDATION

### 4.1 Methodology and Experiments

An experiment in real condition was setup, based on three real BIM models of Bouygues Construction projects from France, in the cities of Paris, Nantes and Lyon. Two of them, Paris and Nantes, mix structure elements (wall, roof, beam ...) and construction methods elements (crane, scaffold, formwork ...). The third one, Lyon, includes plumbing elements (pipes). The three models were created on 3D building design software Revit® and the exported in the real time 3D engine Unity3D®. These elements are automatically classified as structure, method or plumbing elements using a previous building ontology developed for the system.

Four visual scenes were taken for each model, and their associated depth maps were computed. Our system determines the color modification for each user profiles available in the 3D model. As the Paris and the Nantes models mix structural and method elements, four images with enhanced colors for structure engineers and four images with enhanced colors for method engineer were created. For the Lyon model, the same process is applied to obtain four images. There is a total of 20 enhanced color pictures.

The experiments aim at evaluating the benefits of our method with building experts. A questionnaire was proposed to construction engineers, as illustrated on Figure 7. In the experiments, the user profile (structure, method or plumbing engineer) is recorded. Two images of the same visual scene are displayed on screen, chosen randomly from the 3D models: one image is the original, the other one is the color enhanced version. The position, left or right, of the original and modified image is also chose randomly for each presentation. The expert is then asked to choose which image is the most comfortable to work with. The questionnaire have 5 possible choices: left image, probably left image, indifferent, probably right image and right image. The response time for each image is also recorded. An example of the setup is show on Figure 6. The structure and method experts are tested with 8 images extracted from the Paris and Nantes models, while the plumbing experts are tested on 4 images issued from the Lyon model. A total of 21 experts have participated to these experiments: 8 are method engineers, 9 are structure engineers and 4 are plumbing engineers.

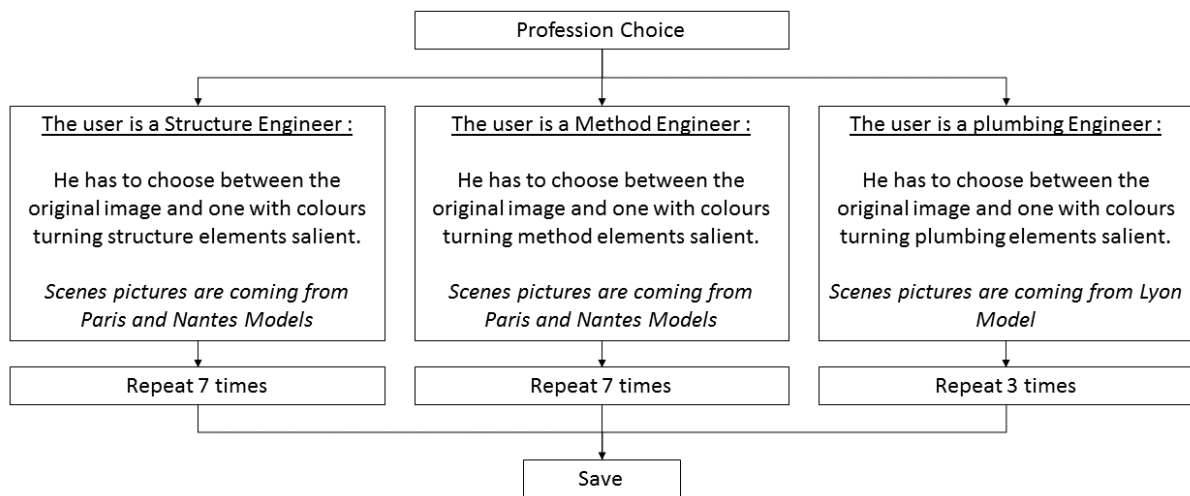


Figure 7: Test protocol for the assessment of the proposed system

### 4.2 Results

The results obtained from the experiments are show on Figure 8. The results are consistent across projects and user profiles. They do not indicate a bias for specific model or for a specific profession. In average, the saliency enhanced image is chosen in 73% of all cases, to be compared with the 9.9% of expert response selecting the original imager. The results confirm that our system improved the visualization quality while maintaining all information on screen. Nonetheless, the 17.1% “indifferent” answers indicate that the have seen the advantage of the system and are waiting for the industrial BIM viewer version.

We applied Wilcoxon’s Signed-Rank test. For each picture, we count the number of engineers who chose the modified or probably modified for the first sample, and those who chose probably the original or the original for the second sample. For the p-value decided to take 0.05 as limit, the p-value result is 0.0001 which confirm the



significance of the experimentation.



Figure 8: Histograms of experts' answers. Bottom: Results for Paris, Nantes, Lyon. Top: Results for structure engineers, method engineers and plumbing engineers.

A limitation appeared during the experiments: the method experts inspecting the Paris and Nantes, from images which are taken from a long distance point of view, the system suffers from a lack saliency enhanced render and in some cases tends to turn irrelevant elements in non-identifiable dark elements. This limitation could simply be addressed by modify the background influence on the saliency measure.

## 5. CONCLUSION AND PERSPECTIVES

This paper describes a system for enhancing the visualization of BIM model, using saliencies to bias the visual focalization on the most relevant elements, given a specific user profile. From the knowledge of BIM managers, we proposed a classifier to sort elements of the model depending of their category regarding per building departments. We described an adapted saliency system to architectural images which implements a perceptivity integration for the orientations map and integrated depth clues. Finally the system will be used in an application for the assistance for BIM engineers. The system adapts model colors to keep the visual attention of the important elements for the user profile. An experimentation was realized and show positively significant results and perspectives for the global improvement.

Future works will be dedicated to extending the system with other type of transformation for improving the visualization. Possible candidates includes transparency and spatial position. It should be noted that the building ontology embedded in the system allow to specifies transformation are allowed and which ae not. The ontology could be improved, to include elements defined as crucial for several departments. Also, the ontology could include some priority information for the visualization of complex objects. The last improvement concerns the

position and orientation of the virtual camera (the user's view), which can help to define appropriate enhancement.

This work was made with the collaboration of Bouygues Construction. The resulting application will be integrated in the future BIM immersive room. The research has been financed in partnership with the ANRT (Association Nationale de Recherche et Technologie).

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