BIM Coordination Room Layout: Assessment Criteria and Metrics

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Abstract
Coordination of BIM-based projects requires distinct media from those used for paper-based analysis. Participants of BIM coordination meetings have new needs as visualizing, navigating or checking 3D models. The objective of this paper is to present criteria and metrics for assessing the quality of BIM Room layouts. Fourteen different layouts were analyzed and evaluated for validating the results on metrics and criteria relating to physical layouts. In order to establish the relative importance of all proposed criteria for fulfilling the needs of BIM meeting participants, as well as the relative scores for the metrics, the AHP multi-criteria decision method based on analysis of comparisons in pairs was applied. The criteria and metrics presented and the methodology to measure them can be useful for evaluation of other rooms and layouts, supporting the design of more appropriate facilities for attending users of project meeting rooms based on BIM.

Keywords: Project Coordination, Building Information Modeling, Metric, AHP.

1 Introduction

A study on the business value of BIM for construction in major global markets shows that, in Brazil, 40% of companies in the design and construction sector that responded to the survey are on an average BIM deployment level, and 70% of these companies have been using BIM for 1-2 years (McGraw-Hill Construction 2014). This is an indicator of the Brazilian advance in this new work process.

Building Information Modeling (BIM) is the process of production, use and update of a building information model throughout the facility lifecycle. This model, in addition to the geometry of the building, contains information about its various aspects, covering all disciplines involved in a project (Santos 2012). BIM models are especially useful during design development. For this, it is assumed collaboration (Leicht 2009). Design collaboration is defined as a process where the designers communicate dynamically among themselves and work together in order to collectively establish design objectives and build their solutions. Collaboration involves teamwork, negotiation and shared representations (Lahti et al 2004). According to this author, the collaborative design process has three characteristic patterns, with variable intensity: coordination, cooperation and collaboration.

The focus of this article is restricted to the design coordination phase and to the infrastructure and physical facilities necessary for the operation of the coordination activities and interpretation of BIM models in face-to-face meetings inside the coordination rooms. It is worth to note that, in Brazil and some other countries, detailed trade coordination is an activity performed by designers and consultants still the design phase and carried out in offices rather than on the construction site.

The design coordination is a multidisciplinary activity to support the design process focused on the management of technical issues and decision making in the design (Melhado et al 2005). This activity usually implies communication among all designers, both inside and outside of meeting rooms. The spaces where the design coordination meetings take place may be physical or virtual (Liston et al 2000) and are used for information sharing and consultation and decision-making on issues of designs. Decision-making in design, most of the time, is still done in person (Liston et al. 2000).

The adoption of BIM in the design phase and the availability of new technologies are driving users to seek alternatives to the infrastructure of the spaces where these meetings are held (Liston et al 2000, Fruchter et al 2006, Dennis et al 2008, Leicht 2009), despite the increasing availability of internet infrastructure enabling teams to hold distance meetings.

The focus of this work is directed to the study of face-to-face meetings emphasizing problem solving, design decisions and reducing the latency period between the meeting participants. In the last twenty years, the format of the meeting spaces has been changing. This change can be explained both by access to new technologies and the design methods, moving from traditional forms of 2D design to three-dimensional parametric object-oriented practices.

In order to identify the activities that most frequently occur in design coordination rooms, a study was conducted on twenty coordination meetings based on analysis of 2D designs (Addor & Santos 2014). It was identified that 48% of the activities that take place within the coordination rooms are related to viewing printed plans by some or all meeting participants. Although this study has been done on meetings based on analysis of paper documents, the conclusion reached was that a large projection screen could supply the majority of the most frequent actions in these meetings. Afterwards, BIM-based meetings were also observed and, as a result, various new user needs were detected due to the change of communication patterns and user behavior towards technology. Those needs were used as a basis for structuring the methodology of this study. Based on the Constructive Research approach (Oyegoke 2011, Kasanen et al 1993), it was determined the main research problem: identify what was the most optimized infrastructure for a BIM coordination room.

The purpose of this article is to show how this methodology to prioritize the needs of users, establish metrics for assessment and perform multi-criteria decision analysis can be applied to define optimized layouts for BIM coordination rooms as well as present validation results.

2 Needs Assessment of BIM Coordination Room Users

Before planning the use of an interactive workspace, it is necessary to understand what are the requirements linked to significant interaction types. These interactions can be of informational or physical character. Some features were identified by Rankin et al (2007) and relate to:

- Viewing documents on large screens;
- Reviewing documents and to interact with information in the meeting room;
- Allowing more effective communication among participants, reducing the loss or misinterpretation of information;
- Supporting electronic documentation and collaborative learning and allowing the team to bring less paper-based information to the meetings;
- Promoting personal interaction on work teams;
- Accessing design information in a more relaxed environment;
- Making use of server and computer network in the meeting room;
- Make use of touch screens;
- Providing permanent and mobile equipment in the room. Permanent equipment includes touch screens, servers, wireless keyboards, wireless mice and laser pointers. Mobile ones include personal notebooks, tablets and smartphones;
- Making video and audio recordings.

Previous research on the theme has focused on the observation of meeting participants with a variety of equipment that provided access to data, simulations, visualization and exchanges among the actual participants, rather than being concerned to anticipate the needs of users or making the space "smart" (Johanson et al 2002, Goldparvar-Fard et al 2006). Based on this type of concept, ten video recordings of BIM design coordination meetings were made and analyzed for this study. The objective of analyzing these recordings was to identify the user needs in relation to physical infrastructure, equipment, furniture and inter-relationship among the participants. In addition to the analysis of video recordings, current technical standards were consulted regarding the ergonomics of the human-system relationship (ISO 9241-210:2010; ISO 9241-11:1998) where the approach to the user experience is the result of the presentation, functionality, system performance, interaction behavior and assistive capabilities of an interactive system, including both hardware and software. The first standard states the need for defining the context of current use of the systems, the characteristics of users, tasks and of organizational, technical and physical environments. These aspects were considered important when capturing meeting room user data, and directed us to:

- Identify the room users;
- Identify what are the characteristics of these users (knowledge, skills, experience, education, training, aptitudes);
- Identify goals and tasks of users within the room;
- Identify the relevant characteristics of the physical, social and cultural environment of users;
- Specify the requirements of users (user needs, context of use, ergonomics, interaction, furniture, infrastructure, space, environmental comfort).

The methodology for capturing the needs of users in BIM coordination rooms also took into account:

- Mapping observations of BIM coordination meetings;
- Technical standards in force;
- First author's experience in more than 25 years of design coordination.

3 Definition of requirements for analysis of a BIM coordination Room layout

Some findings of the study conducted on communication standards and requirements in design coordination rooms (Addor & Santos 2014) have provided the basis for defining the requirements for analyzing room layouts. Although this study has been done on traditional designs (not BIM), it is important emphasizing that only actions that require infrastructure support were considered and that making decisions, solving design issues and ensuring improved designs are the main objectives to be reached, both in paper-based and BIM meetings. In addition to this initial database, video recordings of ten coordination meetings based on BIM were also considered, as prescribed by ISO 9241-2:1992 in the observational study of users to establish the requirements for tasks.

The following user needs were selected to comprise the criteria and metrics to be applied for assessing BIM coordination room layouts:

- Viewing of information: the need of all participants to view a design, an image, a text document, a spreadsheet or a video;
- Interactivity: needs related to communication and interpersonal interaction so that participants can see each other and communicate;
- Infrastructure: the room must have electrical outlets to connect external equipment such as notebooks, tablets or smartphones;
- Furniture: the room must provide comfort and seat for users and support for external equipment and personal items such as notebooks, notepads and tablets;
- Physical Space: the room must provide room for circulation of users, placement of furniture and space to seat people;
- Environmental Comfort: minimum lighting, temperature and acoustic parameters necessary so that users feel comfortable during a meeting.

4 Methodology

The adopted research method involved a literature survey on the issues of the layout criteria listed above, including technical standards and established ergonomics principles. Based on this survey, criteria and metrics for the main needs of BIM coordination room users were defined. These metrics were applied to fourteen layout versions for the room available for the study. These layouts contains the same quantity of tables, chairs and projection screens and accommodate the same number of users. The metrics were applied and scores were established on each layout. To evenly compare these variables, the AHP-Analytic Hierarchy Process method (Saaty 1990) was applied on the criteria and on two sub-criteria levels.

Finally the results were analyzed and a conclusion was reached about which layouts would be more suitable for BIM coordination rooms, taking into account the information viewing, interactivity and physical space criteria. The criteria for electrical infrastructure/network, furniture and environment were not considered in the analysis because they were all the same as only a single physical room was analyzed in the study.

4.1 Proposed Layouts

For this study, a total of 14 layouts were designed all containing 6 tables of 1.20m (length) x 0.60m (width) x 0.77m (height), 12 chairs, two interactive projectors with moveable 96-inch screens, in a meeting room measuring 5.6m x 4.71m, for 12 participants. Considering these elements, the proposed layouts are presented in Figure 1:

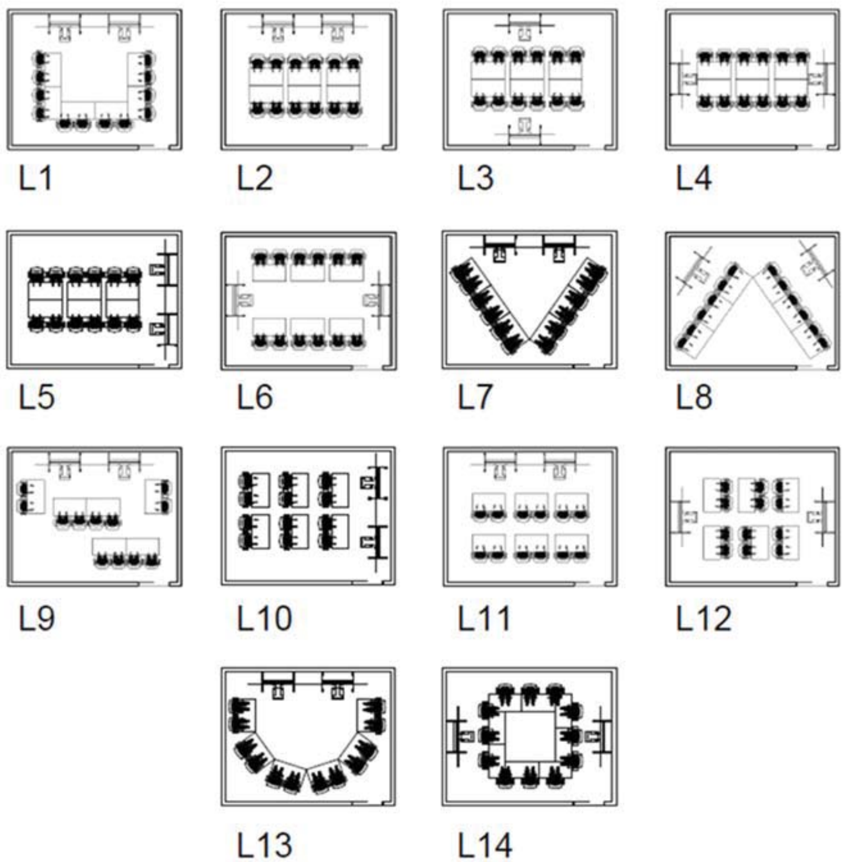

Figure 1 – Proposed layouts

4.2 Proposed Criteria and Metrics

For each of the 6 user needs defined in section 3, criteria and metrics for assessment of layouts were proposed and are described below:

Information Viewing: for this need, three criteria were established concerning the relationship between the meeting participant and the projection screen:

Criterion 1: *for a comfortable view of the screen, the **horizontal angle** at which the viewer has to turn his/her eyes, head and/or body to see the entire display area has to be small.* For an observer not need to move his eyes to see an object or image, the angle variation need to be within 0-20 degrees to each side. If this variation is within 20 and 35 degrees the observer would have to move his/her eyes. If it is within 35 and 55 degrees he/she would have to move his/her head and, if greater than 55 degrees, he/she would have to rotate his/her body or chair. (Panero & Zelnik 1979). Based on these criteria, a metric has been established which measures the angle between the extreme left and right edges of the screen(s) with the observer at the vertex. The angles were categorized into four groups: less than 40 degrees; between 40 and 70 degrees; between 70 and 110 degrees and; more than 110 degrees. The metric is the average angle among all participants. The standard deviation for these angles can also be used as a tiebreaker between alternatives.

Criterion 2: *the **percentage of screen occlusion**, caused by the other participants, perceived by each participant from his/her position in the room, has to be small.* To evaluate under this criterion, the adopted metric was the percentage of the screen blocked by the body to the other participants (assuming a standardized dummy), considering the participant's point of view. To make this measurement, a synthesized image of the room from each seating position was generated in a 3D modeling application (e.g. Revit) and exported to an image processing and analysis application (e.g. Photoshop), where the amounts of occluded and non-occluded pixels in the screen region can be computed (using the histogram tool). The ratio of occluded area to total screen area is calculated to derive the percentage of screen occlusion. Instead of a virtual model, the use of a photo of the room with typical participants would be possible, but this process would take more time and require more work. The metric is the average, for all seating positions, of the occluded screen percentages. Again, the standard deviation could be used as a tiebreaker in the results of the global analysis.

Criterion 3: *the **maximum vertical angle** between the upper edge of the screen and a horizontal line at the observer's height must be small.* To calculate the corresponding metric, this angle is measured in a vertical sectional view from the observer to the center of the projection screen. The angles were categorized in three groups: $0° < \alpha \leq 30°$; $30° < \alpha \leq 50°$; and $\alpha > 50°$ (Panero & Zelnik 1979).

Interactivity: *participants must be able to see and talk to other meeting participants which, therefore, must not be out of sight nor too distant or at their backs.* For this need has been established a criterion that measures the degree of relationship and interaction among meeting participants. For composing this criterion, 3 metrics were defined: **participant obstruction** (zero if the speaker can see or 1 if the speaker line of sight to the listener is obstructed); **distance** (between the speaker and the listener) and the **angle** the speaker has to turn his/her head/body to interact with listeners. For distances four ranges were considered: 0m - to 1.40m; 1.40 to 2.40m; 2.40 to 3.0m and farther than 3.0m. For angles, as well, four ranges were considered: 0° to 45°; 45° to 90°; 90° to 135°, and 135° to 180°. For each of these variables, an angle or distance measurement is to be taken, as well as a occlusion check. The reference for these metrics was obtained by an observational study in design coordination meetings. If there is no listener occlusion, the angle and distance could influence the communication positively or negatively. For example, if the listener is sitting facing the back of the speaker. Despite the close distance (good/positive score) the speaker would have to turn his/her body 180° to face the listener, which would provide a bad score.

Infrastructure: *participants in a meeting room frequently need to plug their personal mobile devices to electrical outlets.* The criterion for this need was related to the amount of general use outlets in the room to connect participant equipment. The metric established three ranges: less than 1/2 outlet per person; from 1/2 outlet to less than 1 outlet per person; 1 or more outlets per person. The reference used for setting this metric was observational study in design coordination meetings.

Furniture: *room furniture must provide adequate space for resting personal equipment and support for note taking activities by participants.* The criterion for this metric was related to the size of support area for portable external devices brought in by meeting participants. The minimum reference size was set to the equivalent of a standard school desk (tablet arm chair) with dimensions of 37cm x 33cm, the minimum base support for a notebook. The metric established three ranges for the measurement of width (W) and depth (D) of the work areas, considering: WxD<37x33cm; 37x33cm<WxD<80cmx61cm and; WxD>81cmx62cm (Panero & Zelnik 1979).

Physical Space: *the circulation spaces should be adequate to avoid interruption of room activities and possible accidents during circulation due to loose wires, table legs and equipment brackets.* This metric aims to ensure there is minimal ideal circulation space for meeting places. The metric established that minimum distances of circulation to be followed were to be classified into four groups: >1.00m; between 1.00-0.80m; between 0.80-0.60m and less than 0.60m (Diffrient et al 1981).

Environment Comfort: *participants must enjoy heathy and comfortable lighting and air conditions inside the meeting room.* The issues related to a comfortable environment are not directly related to the layout of a meeting room. However, they should be considered as a user need and so were adopted as analysis criteria. For a favorable air condition, the temperature should be between 20° C and 23° C (ISO 8756:1994); the noise level should not exceed the range of 30-40 dB(A) (ISO 354:2003); and there should be adequate natural or artificial lighting around 500 lux luminance, unified glare limit of 19 UGRL and 80 RA of minimum color rendering index (ISO/CIE 8995-1:2013).

4.3 Application of metrics to layouts

Five metrics were selected to be applied to layouts. Three were screen-viewing related, one about interactivity among participants and the last one linked to room space as detailed in section 4.2. Those are the only metrics affected by the room layout. The infrastructure, furniture and environment comfort are linked to this feature. The metrics were applied to the 14 proposed layouts. First, horizontal angles were measured according to the criterion and metric #1. As an example, the scores obtained by measuring angles at the participant's positions were classified and color coded in Figure 2.

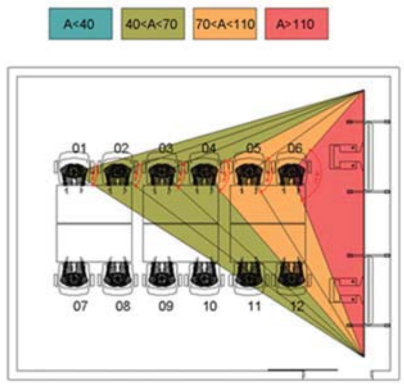

Figure 2 –Horizontal angle measurement

Secondly, the occlusion index (metric #2) was measured. 3D views were produced in BIM software and used to compute the percent of occluded screen area, as shown in Figure 3.

Figure 3 –Screen occlusion index

Thirdly, the vertical angle (metric #3) was measured in sectional views, as in Figure 4.

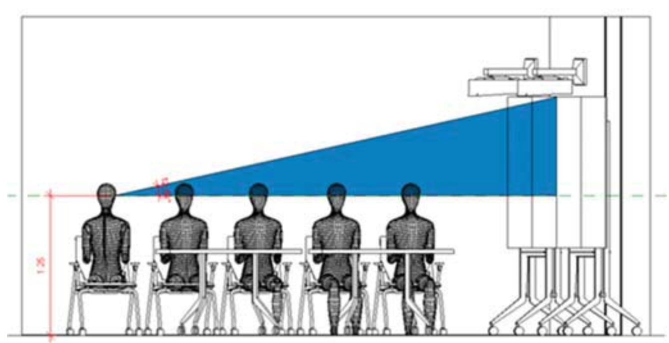

Figure 4 –Vertical angle

Fourthly, the measuring of the interactivity among users with the application of metric #4 was made, registering distance and angle measurements among the meeting participants, as well as occlusion checking. And, finally, the distance measured along a perpendicular line from each seat to the wall was documented (physical space criterion).

4.4 Multi-criteria analysis with application of AHP

In order to understand the relative importance of all participants' needs described in section 3, the AHP - multi-criteria decision method based on analysis of peer comparisons (Saaty 1990) – was used. Using the fundamental scale proposed by Saaty (1990), opinions of 10 participants of design coordination meetings were collected. According to a previous study (Addor & Santos 2014), designers, coordinators and assistant coordinators were the most frequent functions of people present in design coordination meetings. The ten selected participants who responded to pair-comparisons questions had the following functions: 4 design coordinators, 4 designers and two design checkers. All had BIM experience and participated in BIM coordination meetings before. The images projected on the two screens always had different contents.

The relative importance among the viewing, interactivity, infrastructure, furniture, physical space and comfortable environment criteria were analyzed by the 10 respondents, as well as for all sub-criteria of information viewing and interactivity. The main criteria and all sub criteria were evaluated by calculating the normalized eigenvalues and eigenvectors of their matrices. With these 10 normalized values, the final score was obtained by calculating their average. Before calculating the matrix, it was necessary to check its consistency. Saaty (1990) determined through two theorems that the largest real eigenvalue (ƛ max) was equal to the number of components of a square matrix then this array would be consistent. However, this does not always occur. Then the author has determined the consistency index (CI) of a matrix adopting the formula (ƛ-max n / (n-1), where n is the number of rows of a square matrix. He also suggested the use of Consistency Ratio (CR) which is a ratio between the CI and a Random Index (RI) which varies according to the size of the array. In this research, CR values of up to 10% were accepted; otherwise, new judgments were done for increasing the CR.

5 Results

The results were observed according to the pairwise comparison and are presented in Table 1. All data for the comparison matrix were collected and corresponding eigenvectors and eigenvalues were calculated according to the AHP methodology. The average of all eigenvector with normalized relative priority was calculated yielding a relative priority for each criterion. This methodology was also applied to map the ranges of metrics of sub-criteria presented in section 4.2 to relative scores (Saaty, 1990). Those priorities are used as weights to the scores of the metrics of each sub-criterion to compose a criterion score and again in the main criteria for composing a final score for a layout. Each layout has been assessed within each sub-criterion and criterion. After calculating the global weighted sum of all criteria, it was reached a classification for the proposed layout alternatives.

The viewing, interactivity, infrastructure, furniture, space and comfort environment criteria were pairwise compared by ten participants of the meetings. According to them, the major influence factors on the quality of layouts were: the viewing criteria (37.45% of influence on the layout) followed by the interaction (27.3%), as shown in Table 1.

Table 1 Summary of mean vectors of priorities of the criteria and sub criteria

Main criteria	Visualization 0.3745	Interactivity 0.2726	Infrastructure 0.1318	Furniture 0.0763	Space 0.0709	Env. Comf. 0.0739
Sub- Criterion Info Viewing	Observ Mov Horiz Angle 0.2513	% Screen occlusion 0.5573	Vertical Angle 0.1914			
Horizontal Angle Ranges	0 <A< 40 0.5086	40<A<70 0.2978	70<A<110 0.1348	A>110 0.0587		
%Screen Occl. Ranges	0-5% 0.5308	5.1-10% 0.2722	10.1- 15% 0.1459	>15% 0.0511		
Vert. Angle Ranges	0<α<30° 0.7015	30 <α< 50° 0.2108	α>50° 0.0877			

Sub Criterion Interaction	Obstruction 0.2681	Ângle 0.4257	Distance 0.3062	
Angle Ranges	0-45° 0.4908	46-90° 0.3203	91-135° 0.1324	136-180° 0.0566
Distance Ranges	0-1.40m 0.5043	1.41-2.40m 0.2849	2.41-3.00m 0.1517	>3.00m 0.0590
Space Ranges	D>1.00m 0.4632	0.80<D<1.00m 0.3372	0.60<D<0.80m 0.1459	D<0.60m 0.0537

The same pair-wise comparison was made by the participants for the sub-criteria information viewing and interactivity. The main influence on the layout in the info viewing criterion is the percentage of the screen occlusion with 55.7%. For the interactivity sub-criterion, the factor related to the angle that the observer has to turn to interact with another observer had the highest priority (42.5 %).

After the establishment of all criteria and sub-criteria priority factors, alternative layouts were analyzed. The results of the layout analysis were tabulated and weighted by priority vectors found by the multi-criteria analysis. The 4 layouts that received the highest priorities were the L14 (score 1.539), followed by L13 and L1, with scores 1.537 and 1.517 respectively. The fourth best scored layout was L7 (1.514). Full results are shown in Figures 5, 6 and 7.

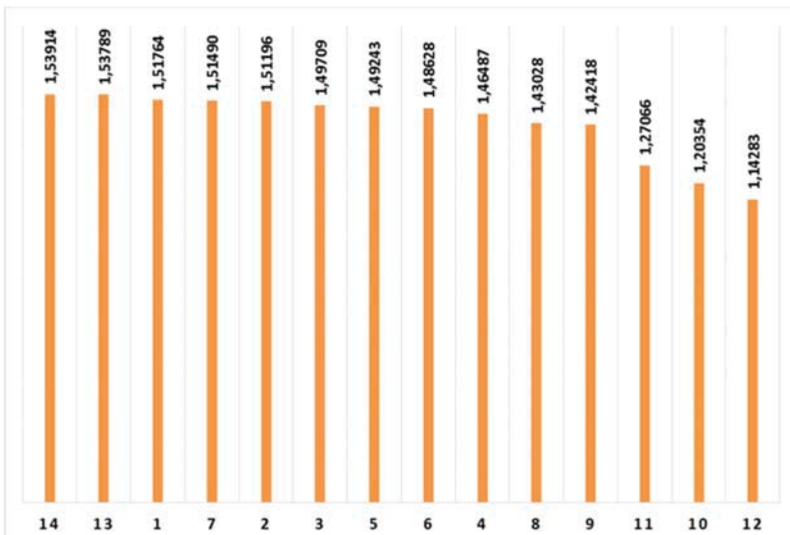

Figure 5 – Layout assessment results

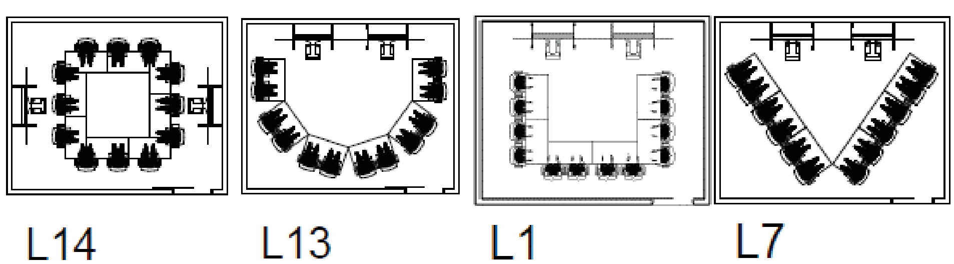

Figure 6 – The top four layouts according to the analysis

Main criteria	Visualization	Interactivity	Infrastructure	Furniture	Space	Env.Con.	**Total**
L14	0.116745	1.133291	0.131799	0.076319	0.007075	0.073905	**1.539137**
L13	0.189082	1.057046	0.131799	0.076319	0.009735	0.073905	**1.537889**
L1	0.133913	1.091355	0.131799	0.076319	0.010344	0,.73905	**1.517637**
L7	0.183969	1.026142	0.131799	0.076319	0.022764	0.073905	**1.514900**

Figure 7 – Scores of the top four layouts according the criteria

6 Conclusions

This paper presented a methodology for defining criteria and metrics for assessment of layout qualities of BIM coordination rooms. Fourteen proposed layouts are analyzed for validating the proposed method. The results have shown that V- and U-shaped layouts were the most efficient ones, according to the criteria investigated. The applied AHP methodology is a descriptive theory of the intrinsic subjective evaluation process and its results need to be adapted to the proposed analysis. The inconsistency imposed by the scale of Saaty (1990), should be considered within a 10% range.

Thus, considering that range, in the case studied, the 4 best layouts assessed must be reviewed in a refinement of the analysis. The layout #14 obtained the best total score despite getting an average low score for visualization, even though there are people back facing on both screens. However, its interactivity mark was maximal as the three sub-criteria that make up the interactivity criteria were well attended and received very balanced marks. In other words, the angle, distance and occlusion between these participants on that layout are good. On the other hand, the L13 obtained a score very close to the L14, and its viewing score was the maximum achieved among all layouts because its performance on the sub criteria of observer movement, % of the screen occlusion and maximum vertical angle are very well attended. However, the mark received for the interactivity criteria “distance” was the worst, which shows that in terms of distance communication, layouts with very open format, type "U" do not respond well to these criteria. On the other hand, the L13 obtained the best score in the interactivity criteria “obstruction” because there is no visual impairment among participants in this layout, which greatly facilitates the interaction between the participants in this type of arrangement. The L1, despite being in third place, obtained the second best score for interactivity and, in this item, it is better than the L13 because there are more people facing each other, which decreases the distance and angle of interaction. The L7, while fourth-placed, has the second best score in the screen display visualization criterion, and there is a balance between the movement of the observer, % of the screen occlusion and maximum vertical angle, showing that for good visualization, layouts in "V "are also a good option.

A factor to be considered in upcoming research is the cost-benefit relationship between alternatives. Although the costs may be included in the decisions, it should be disregarded until the alternatives are evaluated, so that a solution that has great benefits but is too expensive to be implemented can be substituted. Costs of each alternative must be analyzed separately and then judged against their benefits. In the presented case study, all alternatives had the same number of screen projectors, the same size and people capacity and, therefore, a cost analysis would be meaningless. Cost analysis will be useful when analyzing meeting rooms with different equipment, for measuring the cost benefit with different equipment and room sizes.

It is believed that the results of this study can contribute to further research and proposals for improved facilities for better serving BIM meeting users.

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