Usability Analysis in the Liquid Galaxy platform

Ismael Arroyo*, Francesc Giné†, Concepció Roig‡
Distributed Computing Group, University of Lleida
Lleida, Spain
Email: *ismael.arroyo@udl.cat, †sisco@diei.udl.cat, ‡roig@diei.udl.cat

Toni Granollers§
Research Group on Human-Computer
Interaction and Data Integration, University of Lleida
Lleida, Spain
Email: §antoni.granollers@udl.cat

***Abstract*—With the falling price of the technology and the growing trend of cluster display-walls, User Experience (UX) becomes a topic to be taken into account with this new kind of systems. In this context, we present a study of a specific cluster display-wall, named Liquid Galaxy and developed by Google, that covers the three main aspects of usability: effectiveness, efficiency and satisfaction. The study was done by means of a set of tasks that users completed during UX tests, with post-task and post-tests questionnaires, while the system performance was measured. The results show positive feelings from users while using the system. In addition, we relate both system performance and user behavior to estimate whether the system will perform satisfactorily for users. According to our observations, we can see that, in general, there is an intrinsic relationship between the goodness of feelings and the quality of the performance metrics. This relationship can facilitate the inclusion of cluster display-wall systems in a broad range of scenarios with right levels of UX just by analyzing their computational characteristics.**

***Keywords*–Liquid Galaxy; User Experience; Cluster Display-Wall.**

I. Introduction

Cluster-based solutions for creating large displays have recently generated a lot of interest [1]. Such displays have the potential to put high-performance visualization within the reach of more users. The most valuable potential of cluster display-walls is their pixel density, as the images are FullHD on every monitor, providing the system with an incredible overall resolution given the low cost of the hardware required. These systems consist of a number of commodity PCs that are interconnected over a LAN or via low-latency networks like the Myrinet [2]. Thus, visualization of the images across screens in cluster display-walls is carried out by synchronizing the data between the computers in the cluster. Nowadays, besides the fact that conventional PCs can be equipped with powerful consumer graphics cards with multiple outputs, the availability of software packages for clusters makes setting up cluster display-walls affordable. Thus, cluster-based displays are affordable, scalable in resolution, and easy to maintain. This opens a wide range of new possibilities for their use in everyday scenarios in such areas as entertainment or education.

This rising trend for cluster display-walls caught our attention and brought up some questions about how the end-user would feel when using and experiencing these new visualization systems, and how we could estimate the user experience acknowledging the system parameters. In order to answer both questions, we performed user tests to know their behavior by gathering satisfaction, effectiveness and efficiency data. Furthermore, we found a relation between them that enabled us to estimate how users would behave with a cluster display-wall with specific performance characteristics. We noted that there are some works in the literature [3][4] that deal with the

Figure 1. Liquid Galaxy.

desired results separately, but we want to go one step further by relating both metrics.

In this work, we were interested in testing the usability related aspects of a particular cluster display-wall system, named Liquid Galaxy [5], especially on acquiring data from real users. The Liquid Galaxy technology is a cluster display-wall hemisphere infrastructure developed by Google, running the well-known Google Earth application [6], which is an example of a master-slave application. The Liquid Galaxy system is usually made up of three, five or eight displays, each connected to a computer node, and is designed to provide an immersive geographic visualization. Figure 1 shows the Google Liquid Galaxy infrastructure installed in the Technological Park in the city of Lleida (Spain) [7]. The Figure also shows the most commonly used controller, named 3D Space Navigator.

With the Liquid Galaxy infrastructure, in the present work, we carried out a pre-prepared test with 27 people. It consisted of navigating to some well-known places around the world. Additionally, everyone answered some questions about their experience while using the system. Then, we related these answers, which made up a set of qualitative performance metrics, to the quantitative performance metrics that we measured during the test. In order to measure this quantitative metrics, we have used the Visualization Rate (VR) performance parameter which has been presented in previous works [8][9]. VR is a relation between the CPU time used by the system to load all the multimedia data and the total time of the visualization.

In general, the results show that the vast majority of the participants were satisfied and had positive feelings using the system throughout the test. Additionally, we have analyzed the relationship between the user' satisfaction levels and the VR performance metric. The obtained correlation shows that the usability of the system can be roughly estimated by using only the VR in any given field test. This relationship can be

 ISBN: 978-1-61208-468-8

determinant in facilitating an extensive use of such kind of systems, given that the knowledge of system characteristics, directly related to system performance, can give knowledge of what the UX [10] of using the system will be.

The paper is structured as following. Section II enumerates different approaches that other authors developed and describes last works that are and improvement above them. In Section III is presented the case study of Liquid Galaxy. In Section IV is described the method and results obtained for the tests. Section V summarizes and relates the obtained data from the previous tests. Finally, VI concludes the paper and discusses future directions.

II. Background and Related Work

Within the extensive literature on large displays, we focused on studies about User Experience on cluster display-walls. In general, research into this kind of system is focused on the study of the UX, such as the ones presented next.

Bi and Balakrishnan [3] focused on user behavior in large-scale displays and demonstrated that the users preferred this kind of system over single desktops. The authors made participants perform everyday work in a week-long study and compare it with single or dual-monitor desktops. The results are all about subjective opinions and observations from the users, with notes about how they used the system. This study is focused on the preferences of the users while ignoring the system performance.

Tan et al. [11] studied how their system, called Infocockpit, can make information memorable. Infocockpit is a projector-based display-wall with ambient visual and auditory displays that engage human memory for location. In their work, they made users complete semantic tasks that consist in remembering pairs of words and then recalling them. The results are both quantitative and qualitative, as they studied how many words the users could remember in Infocockpit compared with on a desktop computer. Also, participants answered a user satisfaction questionnaire after the tasks. Nevertheless, this approach does not try to relate both metrics using the system performance.

Ball and North [4] studied the effectiveness of a 3x3 large tiled display compared with two smaller displays. They concluded that display-walls that use physical navigation significantly outperform smaller displays that use pan and zoom navigation. They tested both environments with a task with quantitative results based on finding targets of different sizes. Also, they introduced observations that the users made during the test, adding a subtle qualitative study into the research. Despite this, they did not take the system performance into account.

Despite the growing literature on qualitative or quantitative views of the use of a cluster display-wall [12] [13] [14], to the best of our knowledge, there are no studies that focus on establishing a relationship between both metrics. In general, these studies are focused on the results of specific tasks, like completion time or scores, but not on system performance and how it affects user behavior and/or experience.

In previous works, we analyzed the performance of the Liquid Galaxy System in relation to different system parameters such as the scalability, heterogeneity, CPU, RAM, Network requirements, etc. However, we did not tackle neither the quality of use from the user point of view nor its relation with the system performance.

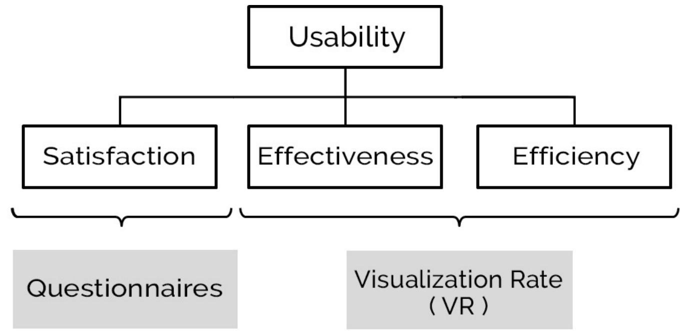

Figure 2. Measuring Usability.

In this paper, our goal is to try to relate the Usability aspects of the User Experience (satisfaction, effectiveness and efficiency [15]) of the Liquid Galaxy cluster. Thus, it will enable us to predict before-hand if a system will perform well enough from the user point of view without the need of carrying out any user test.

III. Liquid Galaxy

Liquid Galaxy [5] is a cluster display-wall that started as a Google project, made up of a custom number of computers, where every node has a single monitor. This system was originally built to run Google Earth [6] and to create an immersive experience for the user. Liquid Galaxy lets you navigate around the globe with its 6-axis controller, allowing you to instantly zoom in, zoom out, and turn in a completely fluid motion. Likewise, the immersive visualization environment of Liquid Galaxy opens up this kind of system to be used by a wide range of applications that can benefit from this feature. Some examples of applications that can be run in this system are WebGL applications like Aquarium [16] or Peruse-a-rue [17], video streaming [18] and video-games like Quake 3 Arena [19].

In the Liquid Galaxy system, every node is connected to the same network and the nodes share a distributed cache named Squid [20], included in the Liquid Galaxy repository. This is used to cache http objects for repetitive use, thus improving throughput, as Internet data requests would be reduced.

Depending on the application to be used, the interaction with the system can be carried out using devices such as a Mouse, Keyboard, Leapmotion, Myo or 3D Space Navigator (as in our case), among others.

IV. User Study

We had the necessity to study the Liquid Galaxy to know how users react to the system and how to try to predict an estimated overall satisfaction by relating it to the performance metrics. In order to achieve this, the system was tested by means of the usability attributes of satisfaction, effectiveness and efficiency [15]. To meet this aim, users had to answer some post-task questions about how they felt after completing each task and a post-test questionnaire about their feeling while using the system. At the same time, the system performance was monitored throughout the tests. This objective is depicted in Figure 2, where it can be seen how effectiveness and efficiency can be monitored using the performance parameter VR, and satisfaction is obtained by using questionnaires that users had to answer.

Figure 3. 3D Space Navigator Movement Options.

With these measurements, system performance and users satisfaction, we aimed to relate both metrics to be able to predict the average usability values for a specific cluster display-wall with given hardware characteristics.

The different aspects involved in the usability tests that were carried out to analyze the system performance and the users satisfaction are exposed next.

A. Environment

1) Cluster Display-Wall: The environment on which the tests were performed was an office equipped with a Liquid Galaxy system made up of 3 nodes. The monitors used in the cluster were a triplet of 32" monitors set vertically in a semi-hemispheric way. The interaction controller used was a 3D Space Navigator (Figure 3), which is the most widely-used controller in all Liquid Galaxy setups. This device is able to displace the view but also rotate it on all 3 axes, making it the most suitable controller for navigating through 3D scenarios.

2) Facilitator: A facilitator was running the test and guiding the participants through it. He/she attended to the participants, explained the goals of the test, the consent form and everything to make them feel comfortable. Once the test started, the facilitator could only answer specific questions or give subtle advice when the participant was struggling to complete a task for a long time.

B. Participants

The set of participants that carried out the tasks included a range of professional profiles, ages and skills with controllers. There were 27 participants in the test, of whom 15 were females and 12 males. Their age ranged from 12 to 68.

Table I shows some information about the participants grouped by age ranges. This corresponds to information about their occupation and the navigation skills they think to have before the test in a range from 0 to 10.

C. Test

Each participant was asked to do a series of four user tasks. The test used to study the User Experience of the system was a semi-guided tour, using Google Earth, around different places across the globe.

The device used to carry out the tasks of the Liquid Galaxy was the 3D Space Navigator of Figure 3. As we knew that this is a different and more complex controller than a common mouse, we dedicated some minutes helping the participants to use the device before starting the test to avoid any initial fear.

The users were also informed that all the information would be given through the monitors during the test and that they will have to answer the questions from the facilitator by voice, who wrote them down instead of the participant to avoid interference with the test.

For each participant, the test was composed of four tasks, each one corresponding to navigating to one of the following well-known places in the world:

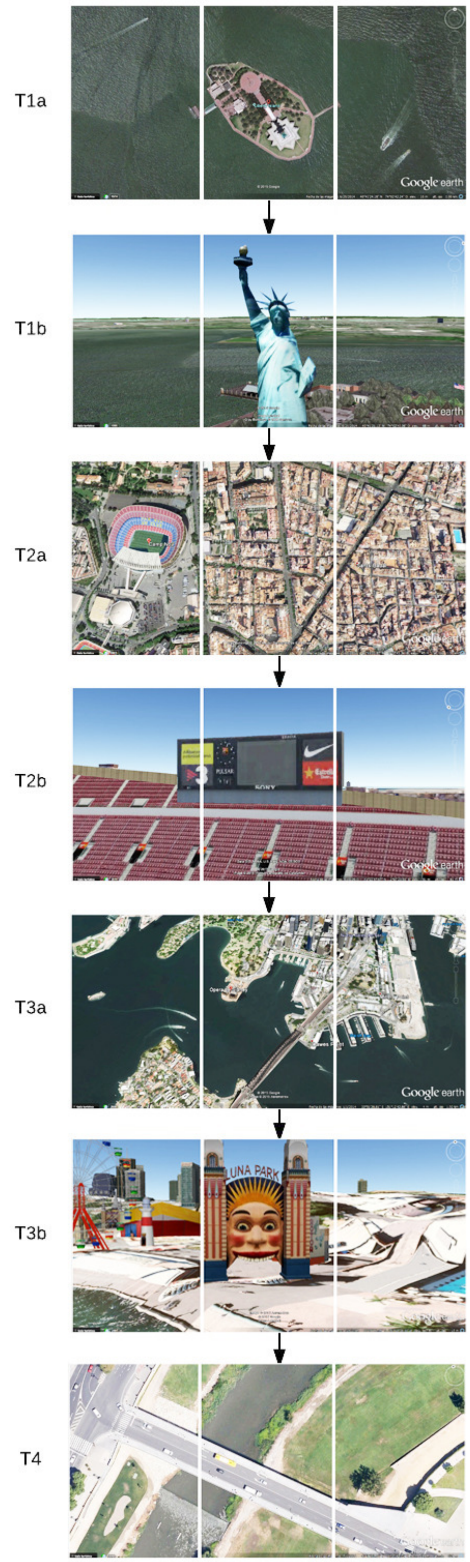

Figure 4. Tour Flowchart - T1a Statue of Liberty from above - T1b Statue of Liberty's crown - T2a Barcelona Football Club stadium - T2b The stadium's screen - T3a Sydney Harbour - T3b Luna Park - T4a Lleida bridge. Each picture is the composition of the 3 screens of the system.

TABLE I. BASIC PARTICIPANT INFORMATION.

Age range	*Participants*	*Avg Skill Level*	*Occupations*
12 to 16	4	7	4 Students.
16 to 21	3	9	2 Computer Science Programmers, 1 Computer Science Engineer.
22 to 35	9	6	3 Computer Science Students, 1 Pre-School Ed. Student, 1 Economics Student, 1 High School Student, 1 Restorer, 1 Industrial Engineer, 1 Computer Science Engineer.
36 to 68	11	4	5 Teachers, 4 management staff, 1 Customer Service Worker, 1 Shop Assistant.

TABLE II. DESCRIPTION OF TEST TASKS.

Task	*City*	*Sub-task*	*Positioning*	*Questions*
T1	New York	T1a	Automatic	How many vertices does the base of the Statue of Liberty have?
		T1b	Manual	How many points does the crown of the Statue of Liberty have?
T2	Barcelona	T2a	Automatic	What does it say on the Barcelona Football Club stadium stands?
		T2b	Manual	What brand is the screen in the Barcelona Football Club stadium?
T3	Sydney	T3a	Automatic	How many buildings is the Sydney Opera House made of?
		T3b	Manual	Find a structure nearby with a clown's face on it. What does it say above it?
T4	Lleida	T4	Manual	How many buses are crossing the bridge in front of the cathedral in Lleida?

TABLE III. POST-TEST QUESTIONNAIRE.

Questions	*Description*
FQ1	”From 0 to 10, mark your personal skill at using joysticks and remote control devices”
FQ2	”From 0 to 10, mark the ease of use when using the system”
FQ3	”From 0 to 10, mark how much you think that you had to learn to use the system”
FQ4	”From 0 to 10, mark how much technical help you think would be needed to use the system”
FQ5	”From 0 to 10, mark if you believe that everyone could learn the system quickly”
FQ6	”From 0 to 10, mark your personal satisfaction when using the system”
FQ7	”From 0 to 10, mark how secure you felt when interacting with Liquid Galaxy”
FQ8	”From 0 to 10, mark the degree of difficulty that you found for using this system”
FQ9	”From 0 to 10, mark your perception of system complexity”

- T1: New York (USA): Statue of Liberty.
- T2: Barcelona (Spain): Barcelona Football Club Stadium.
- T3: Sydney (Australia): Bay of the Opera House.
- T4: Lleida (Spain): City where the participants live.

Tasks T1, T2 and T3 were composed of two sub-tasks. In the first sub-task (Tia), the system positioned itself automatically

Figure 5. Emotional Choices (source LemTool).

at the first place in the city, so that participants had to answer the related question. In this way, the participants did not use the controller for the first part of each task. However, in the second sub-task (Tib), they had to use the controller to reposition the view to be able to answer the related question. Task T4 consisted of a free flight from Sydney (T3b) to a specific point of interest in Lleida city. Figure 4 shows the pictures of the 7 sub-tasks that correspond to the flow of activities in the test.

Table II shows the questions that users had to answer to complete each sub-task, thus completing each of the tasks. Even though the real answers were not so important, they were a way of forcing the user to interact with the system and show interest when doing the tasks. The tasks were designed to increase the difficulty gradually on each step and thus help the users' ability to control the 3D Space Navigator to progress.

After each task, with the aim of acquiring information to evaluate the UX with the minimum set of questions, we issued the same two questions to the participants:

 ISBN: 978-1-61208-468-8

TABLE IV. RESULTS OF Q1 QUESTION.

Tour	*Joy*	*Desire*	*Fascination*	*Satisfaction*	*Sadness*	*Disgust*	*Boredom*	*Dissatisfaction*
NY	7.1%	7.1%	35.7%	42.9%	7.1%	0%	0%	0%
BCN	7.1%	14.3%	21.4%	42.9%	0%	7.1%	0%	7.1%
SYD	7.1%	0%	28.6%	57.1%	0%	0%	0%	7.1%
LL	7.1%	14.3%	35.7%	42.9%	0%	0%	0%	0%

TABLE V. RESULTS OF Q2 QUESTION.

Tour	*0*	*2*	*4*	*6*	*8*	*10*
NY	0%	0%	0%	14.3%	42.9%	42.9%
BCN	7.1%	7.1%	7.1%	28.6%	42.9%	7.1%
SYD	0%	7.1%	7.1%	7.1%	50%	28.6%
LL	0%	0%	7.1%	14.3%	35.7%	42.9%

- Q1: ”From the following drawings, mark which one better explains how you felt when performing the task”. The drawings (Figure 5), based on the LemTool emotional tool [21], are designed to acquire the user's emotional state just after solving each task. Among others, LemTool is an auto-report tool that can be used during the interaction with the interface for its evaluation. It allows the interface to be related to the emotion evoked. The tool consists of eight figures that represent four positive and four negative emotions, combining facial expressions and body postures.
- Q2: ”From 0 to 10, mark your satisfaction with the load timeout of the images”. The possible answers were ”0, 2, 4, 6, 8 or 10. The goal of this question is to obtain a fast and a first-hand opinion related to the satisfaction with the image loading time which is directly related to the VR parameter as will be explained in Section IV-E.

Finally, after finishing all four tasks, participants had to answer the post-test questionnaire, shown in Table III. This last questionnaire is inspired by the System Usability Scale (SUS), which has long been accepted as an industry standard [22] and adapted to fit in our tests with the Liquid Galaxy system.

D. Satisfaction Results

By processing the answers from the questions of the participants (see Tables II and III), we obtained a set of qualitative measures of the test that are presented next.

Table IV shows the level of satisfaction (question Q1) when performing the tests in New York (NY), Barcelona (BCN), Sydney (SYD) and Lleida (LL), while Table V shows the feeling of the users about the waiting time for each task (question Q2). We can see that the majority of the participants provided positive responses when using the system while doing the tests whenever everything was functioning and the waiting times were short. In general, 90% of the participants gave positive feeling responses to the tours of NY, SYD and LL, having a few cases of discomfort. However, this percentage was lower in BCN because the user had to move the Google Earth view into a view showing a significant portion of the city buildings, thus, making the application download a considerable amount of data. Because of this, some people felt that they had to wait much longer than in other tasks, especially the most demanding users, including the youngest participants or those with more technology knowledge. As a consequence, the results of BCN in Table IV shows 14.2% of participants as having negative feelings. This correlates with the waiting time shown in Table V, where in the case of BCN, 21.3% considered the waiting time unacceptable (values lower than 5). Despite some people being frustrated by the wait, they answered more positively in the question Q1 than expected. This leads us to think that they were enthusiastic about the system as it was new and fun for them. We can also say that many of them found the system challenging, but not impossible, forcing themselves to perform better and reward themselves with pride, which could affect the results by giving higher values.

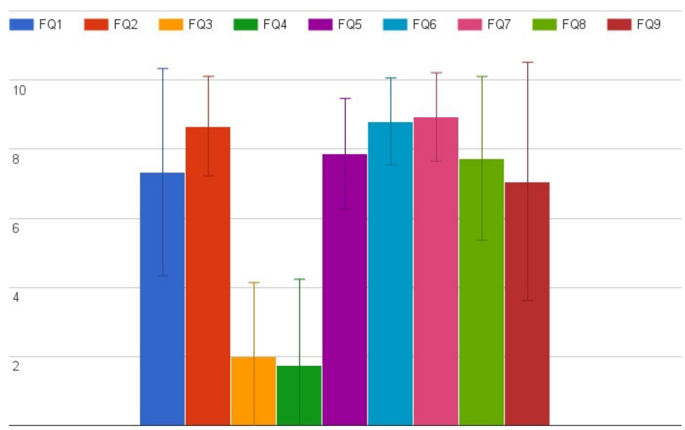

Figure 6. Mean and Error bars from Post-Test questions - Skilled Group.

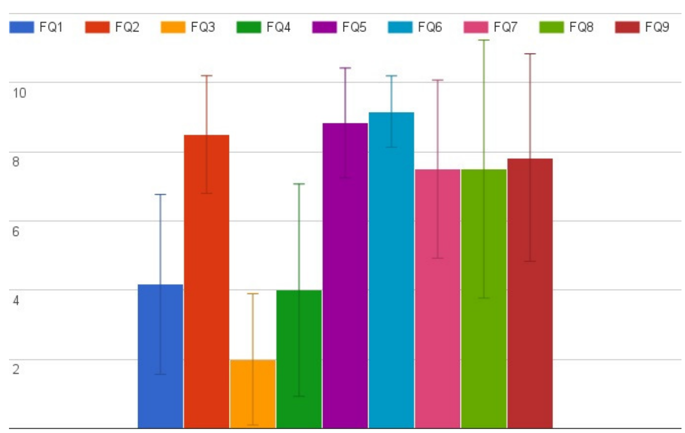

Figure 7. Mean and Error bars from Post-Test questions - Less Skilled Group.

The answers obtained for the post-test questionnaire described in Table III can be divided into two main groups: a young and more skilled profile corresponding to the 12

 ISBN: 978-1-61208-468-8

to 35 age range in Table I, whose answers, in average, are presented in Figure 6, and older and less skilled people, whose answers are presented in Figure 7. This skill difference can be observed with the answer to question FQ1 in both Figures. Taking the answers to FQ2 and FQ3 into account, both groups stated that they did not feel a need for prior knowledge and that the system was easy to learn and use, regardless of their experience. The main difference was about how secure they felt while using the system (FQ7), where the second group, less experienced, felt less secure as well as noting that they needed more technical help. Also, the differences between both groups in their response to the question about whether they thought technical help would be needed (FQ4) were remarkable, which is correlated with their technical skill level.

In relation to the deviation of the answers, we can see that, in general, this was higher in Figure 7 due to the differences between participants in this group, both in age and occupation. Likewise, it is worth pointing out that the question about how complex they felt the system was (FQ9) is the one with a wider range of opinions in both groups. This is because some of the participants did not know what to answer as it was a new system and it lead them to think that it would be too complex for others. Thus, some answered thinking about other people with less or similar experience than themselves. This behavior was expected as the questions were designed to take into consideration other people evaluating the system, and not how they used it.

E. *Effectiveness and Efficiency Results*

As stated in the introduction, one of the goals of the present work was to establish a relationship between the satisfaction (associated with the subjectivity of the participants) and the effectiveness and efficiency measures, related to the system performance (with no subjectivity associated). In our context, we understand the effectiveness as the ability of the system to load all the images while running the application, and the efficiency as the time required to load these images. In order to get the effectiveness and efficiency of the system, the Visualization Rate (VR) metric was used. This metric was used in our previous works to measure the Liquid Galaxy performance [8][9].

Taking into account that the CPU usage tells us when the system has loaded all the visual elements, VR is calculated as the average CPU idle time for a cluster of n nodes with the following equation:

$$VR = \frac{100}{n}\sum_{i=1}^{n}\frac{T\_idle_i}{T\_total}, \quad (1)$$

where T_total is the total time of the test and T_idle_i is the time when the CPU load of node n_i is below a minimum threshold. Note that a CPU load below this threshold means that the CPU is idle and the images have been fully loaded. This procedure can is illustrated in Figure 8, where the blue line near 5% CPU Usage is the threshold for this particular case. The peaks depicted in this Figure corresponds to when the CPU is processing the imagery and the values that drop below the threshold represent when the CPU becomes idle. The CPU usage information was gathered every second from the information given automatically by the system monitor. Note that when the VR is near 100%, it denotes a high visualization rate and, so, good user perception as images are fully visualized, while having a VR equal to 0% means that the data has not been fully loaded and, thus, it has been ineffective. Any value between 0% and 100% indicates how efficiently the system has performed. Given that the best feature of the system is its high pixel density visualization, if the system reports VR results near 0%, it will mean that the user does not take all the potential of the cluster.

TABLE VI. VR RANGES FOR T1a, T2a AND T3a SUB-TASKS.

Tour	*0-5%*	*5-10%*	*10-15%*	*15-30%*
NY	28.6%	42.9%	21.4%	7.1%
BCN	57.1%	35.7%	7.1%	0%
SYD	14.3%	57.1%	21.4%	7.1%

The system performance metric was monitored throughout the test, but only the tasks where comparisons could be made were recorded. Those tasks are the ones that are guided, because Google Earth follows the same path from one place to another in a guided task independently of the user, thus providing fully comparable values. This is not applicable when the user moves between locations manually, as it is almost impossible to have the same flight path for the same step, even with the same user. This means that only tasks T1a, T2a and T3a, depicted in Figure 4, were monitored to calculate the VR.

Table VI shows the VR values obtained by different users for NY, BCN and SYD for the first part of their respective tasks (Tia). For simplicity, these values are categorized in ranges which are shown as columns in the Table. For the case of NY and SYD, the highest VR values were near 25%, but for BCN, the VR achieved lower values. This is due to the fact that in BCN, in Task 2a, a lot of 3D buildings had to be rendered in order to view the desired place and, as a consequence, the loading time was higher and the users did not need to have the images fully loaded to answer the question. Another point to highlight is that all VR values were below 30%. This is because, in our test, the user only wanted to answer the questionnaire, and he/she was not interested in the specific imagery. In a free flight around points of interest by a given user, he/she would spend more time looking at a specific point, which would increase the VR metric.

V. Discussion

User tests were carried out on a Liquid Galaxy cluster in order to study the relation between the system performance and the personal satisfaction of the users when using it. In general, the results showed that there is a relation between VR values and the users' satisfaction level. From our study, we can see that SYD had the highest VR and also the highest satisfaction level, whereas BCN had the lowest VR and level of satisfaction. Despite this, people were generally satisfied and happy to use the system even though the VR values were rather low. This behavior is reflected in the results obtained from BCN. Table IV shows that the majority were satisfied and fascinated (71%), while Table VI shows that the VR of this city was the lowest, always below 15%. These data give us a hint that there might be a relation between VR and the Q1 and Q2 questions. Therefore, the possible relation between the performance and the satisfaction parameters were studied under a statistical point of view.

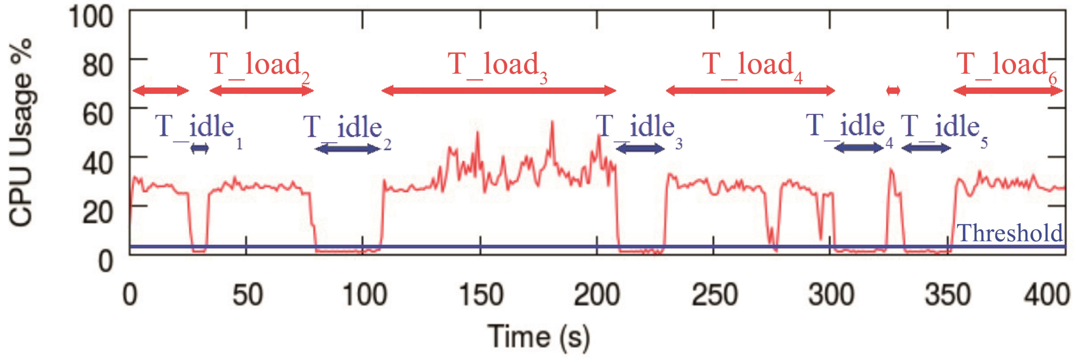

Figure 8. VR: CPU Usage.

TABLE VII. VARIANCES AND CORRELATIONS FOR Q1, Q2 AND VR.

Tour	σ^2_{Q1}	σ^2_{Q2}	σ^2_{VR}	$\sigma_{Q1,VR}$	$\sigma_{Q2,VR}$	$r_{Q1,VR}$	$r_{Q2,VR}$
NY	0,88	1,40	6,48	3,70	5,59	0,65	0,62
BCN	5,34	1,91	3,04	2,49	1,73	0,15	0,30
SYD	1,23	1,69	4,16	2,67	4,43	0,52	0,63

Table VII shows the variances (σ^2), covariances (σ) and linear correlations (r) for the answers to Q1 and Q2, and the VR performance metric. As for the correlation, values closer to 1 or -1 means that there is a strong relation between the metrics, while having values closer to 0 means that there is no relation between them. We can see that, in general, there is a positive correlation in all the cases. Likewise, as it was expected, both correlations (r_{Q1VR} and r_{Q2VR}) in NY and SYD are very strong, while correlations in BCN are the weakest. The reason of this lowest correlation in the BCN case is that in one hand it had the worst VR values due to the high number of 3D buildings to be loaded, but, on the other hand, people maintained a high interest and satisfaction when flying above Barcelona because it was the most well known tour for the spanish users. In addition, it is worth pointing out that, in general, the correlation r_{Q2VR} is slightly stronger than the r_{Q1VR}. This behavior is normal given that the Q2 question asked to the users about their feelings in relation to the loading time and the VR metric was calculated from the same loading time.

These correlation results lead us to think that the VR metric constitutes an orientative value to know the minimum required performance to guarantee a right satisfaction to the user with the system.

VI. Conclusion

This paper is focused on the User Experience study of a specific cluster display-wall, named Google Liquid Galaxy, by using the well-known usability standard definition which enclosures the usability as satisfaction, effectiveness and efficiency. We studied the effectiveness and efficiency using the quantitative metric VR, and the satisfaction using two post-tasks questions about satisfaction using LemTool and a post-test questionnaire based on the SUS and adapted to suit in our study. Additionally, we carried out an analysis to find the relationship between these measurements.

The satisfaction analysis was based on a series of tasks carried out with real users with different characteristics of age, occupation and skills. The results showed that the majority had positive feelings while using the system, even though they noticed a lack of speed in loading images in some parts of the test. Moreover, there was a clear difference between younger and older people. The first group are more experienced and tend to be more impatient, as they are already into this kind of technology, whereas the second group usually are less experienced and tend to be more impressed.

To acquire knowledge of system performance, we used the Visualization Rate (VR) metric that indicates the average CPU idle time of system nodes, in such a way that the time intervals when the CPU is idle (under a certain threshold) means that the images were fully loaded. A VR value equal 0% means that the system is ineffective and any value above 0% describes the percentage of efficiency of the system. During the tests, we observed that the VR was generally below 30% and above 0%. Although this could seem a low performance, it was due to the behavior of the participants when completing the tasks. Some users had only to wait to load partially the image to be able to answer the questions (usually the center screen, excluding the rest of screens) and for this reason the VR values were relatively low.

Finally, we analyzed the existing relationship that could be established between the results of the study. We were able to confirm that the VR constitutes an orientative value of what the satisfaction level will be when using a specific system infrastructure. This was confirmed by the statistical correlation between VR and the questionnaires. It shows how both satisfaction post-task questions are related to the VR values achieved in those tasks. Additionally, satisfaction levels can be higher than expected, taking the VR metric into account, whenever the tour was of high interest for the users.

Our results reveal that with the knowledge of the system performance, which can be found with objective metrics, we can estimate the suitability of a cluster display-wall to be used under certain user requirements. This is very encouraging results for us, as it can facilitate the spread of the use of the Liquid Galaxy platform to a broad number of users and fields (education, professional, research, etc.).

Future work includes mathematical modeling of the predictable system performance, specifically the VR metric, of any given hardware and configuration. Also, we plan to run a similar test in an everyday context such as a travel agency, where participants (potential clients) will use the system to extend the information of their travel plan. We think that this test context will provide us with more realistic data as the users will not perform predefined tasks and, thus, they will try to achieve their personal objectives. Thus, the VR values probably would be different in relation to the ones obtained in our test. One step further could be applying this methodology of measuring the usability in other systems by finding their own VR parameter.

ACKNOWLEDGMENT

*This work was supported by MEyC-Spain under contract TIN2012-37826-C02-02 and TIN2014-53234-C2-2-R

REFERENCES

[1] Nirnimesh, P. Harish, and P. Naraayanan, “Garuda: A scalable tiled display wall using commodity pcs.” IEEE Transactions on Visualization and Computer Graphics., vol. 13, no. 5, 2007, pp. 864–877.

[2] N. J. Boden et al., “Myrinet: A gigabit-per-second local area network,” IEEE micro, no. 1, 1995, pp. 29–36.

[3] X. Bi and R. Balakrishnan, “Comparing usage of a large high-resolution display to single or dual desktop displays for daily work,” in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 2009, pp. 1005–1014.

[4] R. Ball and C. North, “Effects of tiled high-resolution display on basic visualization and navigation tasks,” in CHI’05 extended abstracts on Human factors in computing systems. ACM, 2005, pp. 1196–1199.

[5] Google, “Liquid Galaxy live demo at TED,” 2010, lecture Notes in Computer Science, Springer.

[6] ——, “Google Earth,” 2013, retrieved: March, 2016. [Online]. Available: http://www.google.com/earth/index.html

[7] Ponent 2002, “G-liquid galaxy,” 2012, retrieved: March, 2016. [Online]. Available: http://www.g-liquidgalaxy.com

[8] I. Arroyo, F. Gine, C. Roig, and M. Gonzalez, “User experience on heterogenous liquid galaxy cluster display walls,” in 2014 IEEE 15th International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM). IEEE, 2014, pp. 1–3.

[9] I. Arroyo, F. Giné, C. Roig, and T. Granollers, “Analyzing google earth application in a heterogeneous commodity cluster display wall,” Multimedia Tools and Applications, 2015, pp. 1–26. [Online]. Available: http://dx.doi.org/10.1007/s11042-015-2859-z

[10] ISO DIS, “9241-210 (2008): Ergonomics of human system interaction-part 210: Human-centered design for interactive systems,” International Organization for Standardization, 2008.

[11] M. Czerwinski et al., “Toward characterizing the productivity benefits of very large displays,” in Proceedings of INTERACT, vol. 3, 2003, pp. 9–16.

[12] B. Yost, Y. Haciahmetoglu, and C. North, “Beyond visual acuity: The perceptual scalability of information visualizations for large displays,” in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ser. CHI ’07. New York, NY, USA: ACM, 2007, pp. 101–110. [Online]. Available: http://doi.acm.org/10.1145/1240624.1240639

[13] A. Endert, C. Andrews, Y. H. Lee, and C. North, “Visual encodings that support physical navigation on large displays,” in Proceedings of Graphics Interface 2011, ser. GI ’11. School of Computer Science, University of Waterloo, Waterloo, Ontario, Canada: Canadian Human-Computer Communications Society, 2011, pp. 103–110. [Online]. Available: http://dl.acm.org/citation.cfm?id=1992917.1992935

[14] C. Andrews, A. Endert, and C. North, “Space to think: Large high-resolution displays for sensemaking,” in Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, ser. CHI ’10. New York, NY, USA: ACM, 2010, pp. 55–64. [Online]. Available: http://doi.acm.org/10.1145/1753326.1753336

[15] ISO DIS, “9241-11 (1998): Ergonomic requirements for office work with visual display terminals (vdts)-part 11-guidance on usability,” International Organization for Standardization, 1998.

[16] Greggman and H. Engines, “Aquarium WebGL,” 2009, retrieved at 2015-06-07. [Online]. Available: http://webglsamples.org/aquarium/aquarium.html

[17] Google, “Liquid galaxy website,” 2013, retrieved: March, 2016. [Online]. Available: http://blog.endpoint.com/2013/11/liquid-galaxy-and-its-very-own-street.html

[18] “Panoramic Video Streaming,” 2012, retrieved at 2015-06-07. [Online]. Available: https://code.google.com/p/liquid-galaxy/\\wiki/PanoramicVideo

[19] OpenArena Team, “OpenArena (Quake 3 Arena),” 2005, retrieved at 2014-12-01. [Online]. Available: www.openarena.ws

[20] Squid Team, “Squid web proxy cache,” 2002, retrieved at 2015-06-07. [Online]. Available: http://www.squid-cache.org

[21] G. Huisman and M. Van Hout, “The development of a graphical emotion measurement instrument using caricatured expressions: the lemtool,” in Emotion in HCI–Designing for People. Proceedings of the 2008 International Workshop. Citeseer, 2008, pp. 5–8.

[22] J. Brooke, “Sus: a retrospective,” Journal of Usability Studies, vol. 8, no. 2, 2013, pp. 29–40.

 ISBN: 978-1-61208-468-8