A Visualization of Network Data
Combining 2D and 3D Features

Rita Moreira
Instituto Superior Técnico
Lisbon, Portugal

ABSTRACT
The large amount of data network produced every day and its correct analysis and visualization is crucial, especially for telecommunication companies that request simulations to predict and avoid possible problems. A solution that allows the participant to visualize this information in an efficient and effective way is then necessary. With this work we tried to understand whether, by taking the advantages of both 2D and 3D, a hybrid technique is a viable solution. In order to do this, we analyzed different techniques, characteristics, and displays used for presenting information. We then performed several interviews to network data specialists to better understand who would benefit from this solution and what it should focus on. The process of the development of the prototypes is then explained and finally, qualitative and quantitative tests were performed. From these we were able to conclude that the hybrid prototype performed better on the spatially complex task and, although it has more features than the 2D prototype, it didn’t perform worse, obtaining results very similar to the latter. People also manifested their preference to the hybrid prototype.

KEYWORDS
Network Data; information visualization; 2D; 3D; Hybrid; Telecommunication; Prototype.

1 INTRODUCTION
Technology has suffered a major evolution throughout the years and its usage has become a daily part of our lives. It is almost impossible not to come into contact with some type of equipment or gadget and for some, it is even inconceivable not to use them. It’s everywhere around us and affects several sectors of society like transportation, communication, entertainment, health, etc.

Global telecommunication networks and services have one of the highest volumes of real-time data [8] [6] [7]. Understanding and analyzing all this data is crucial since it not only can be a way to manage and improve network performance and reliability from a customer’s viewpoint [8] but also because it can provide a competitive advantage [6].

There are already tools that aid expert analysts interpret network data. However the same can’t be said about the customers (usually telecommunication operators) who request these analyses.

Current techniques are still insufficient to display this information to them in an efficient way. Therefore, using the correct type of tools and visualization can dramatically change this task, leading to an improvement in performance, making it less time consuming and overall less dull. In a more global perspective, it would result in an “improvement of service to customers, market analysis and gaining an understanding of previously hidden relationships between and within data segments” [6].

Along with Nokia, we aim to understand what the best solution for representing telecommunication data to clients is, especially which type of visualization, since each one (2D or 3D visualization) has its own advantages and disadvantages depending on the type of information that is being displayed. While a simple bar chart may be best represented when shown in 2D because of its simplicity, something that requires more immersion or is very spatially complex may benefit from being displayed in a 3D view.

The main objective of this work is to discover whether or not a hybrid environment is the most appropriate solution to visualize telecommunication data, by analyzing the advantages of using a combination of 2D and 3D techniques and to create an exclusively 2D prototype and a Hybrid Prototype to test this hypothesis. We expect to improve the user’s experience by giving the user a means to search and analyze data in a more efficient and effective way and to reduce the amount of time spent on unnecessary tasks.

2 RELATED WORK
The most fitting approaches and techniques used to present this information can vary, since some may be more advantageous in a 2D display, while others in a 3D or even a hybrid one. So not only do we need to understand which techniques work better for the visualization and interaction of information, but we also need to understand what the most appropriate technology to do it in is, in order to guarantee the best results. Besides this, it is also necessary to understand what particular techniques are used in telecommunication data.

Additionally, it is necessary to understand what the benefits and problems of using 2D or 3D views are, in order to pick these technologies and techniques.

There are several techniques used for information visualization. These range from navigation ones, like panning and zooming, which are particularly useful when it is not possible to display the whole information from a single viewpoint [14] [16]; to highlighting, which allows information to stand out in a design from the remaining information and can be achieved by changing the appearance of said information [20]; to linking which, as the name indicates, creates a link (through highlight or brushing) that allows a common element to suffer some kind of contrast in all views [15] [16]; to distortion [14] and rotation [1]. Some take advantage of both types of visualizations as is the case of the Orientation Icon, or
the ExoVis, that combine 2D slice details with a 3D representation, offering the participant flexibility since they can display multiple datasets [19] [18].

Regarding the technologies used to display information, several can be used, although each one has its own advantages and disadvantages.

**Desktops** are inexpensive, have become very pervasive in our everyday lives and have high quality resolution, which are great advantages [2]. However they are not optimal for visualizing large amounts of data [11].

**Virtual reality headsets** are best for providing immersion and have suffered improvements throughout the years [10], but don’t have a high resolution yet, may cause its participants nausea and are not yet a commodity [4].

**CAVE 2** (for Cave Automatic Virtual Environment 2, a cylinder that incorporates 72 panels, providing a panoramic view, can improve the perception of large-scale 3D datasets (as a result of its high resolution) and be viewed by a large group of people [15]. Nonetheless, they have a considerable size, are very expensive and require a great amount of processing [9].

Finally, **Tiled-displays**, which are composed of several monitors, are a great option to perceive context and details when viewing massive amounts of data in an effective way. Monitors are easily calibrated, have a high-quality resolution but it is still required to have several of them. Although less expensive than CAVE 2, it is still a costly option [16].

Since network data is characterized by its large data set, particular techniques and tools are used to visualize it, so analysts can better view and interpret results. SWIFT-3D is a tool that has a series of visualization techniques (from statistical display to pixel-oriented overviews with interactive 3D-maps and drag and drop query tools) and takes advantage of both 2D and 3D views [6] [8] [7].

To do this we compared several characteristics such as occlusion (a problem very typical in 3D views, but not as much in 2D) [5] [21], clutter (that happens when a great amount of information is displayed in a limited space, which is common in 2D but not so much in 3D) [15] [21] [10] [17], implementation (usually easier for 2D interfaces, since it doesn’t require such an intensive computation as 3D ones) [13] [17], immersion (much more well suited and achieved in 3D) [3], spatial complexity (harder to discern complex environments in 2D than in 3D) [9], participant adaptation (better in 2D representations, since they are more familiar to participants than in 3D) [10] [17], and fatigue (that although can happen in both visualizations, tends to occur on immersive 3D devices from time to time) [13].

From analyzing the previous sections, it’s possible to conclude, that some of the weaknesses from a type of visualization can be solved by using another visualization (e.g. how occlusion is a problem in 3D but not in 2D).

Since telecommunication data is characterized by its large amount of information and need for spatial visualization of maps (which can be hindered if 2D is used), it is possible to conclude that both 3D’s and 2D’s particular features can be put to use in order to better visualize this data.

Using a hybrid visualization is therefore what we believe would be best suited to present and visualize telecommunication data since it takes advantage of both 2D’s and 3D’s best traits avoiding specific problems characteristic to these visualizations. This way, common problems in 2D, like presenting large amounts of information (typical in telecommunication data) that would cause clutter, can be bypassed by using 3D. However, analyzing details of such large amounts of data is also an important task and therefore abstract elements like text are also necessary (which is where 2D comes in).

Another great advantage is also the fact that an overview of the information provided by 3D is possible, which can be complemented by linking it to the details provided by 2D representations. Using the strengths of 2D and 3D allows a scalable visualization for large and heterogeneous datasets [15].

Having both representations can also provide a superior performance when compared to strict 2D or 3D. However, this combination has to be balanced in order to avoid an increase of the complexity of the display. When compared to the strict displays, tasks which required precision were better in environments that combined 2D and 3D. This latter also performed as well or better, inspired higher confidence and allowed a more integrated navigation than strict 2D. Accuracy also improved, although its level may vary depending on the technique which is used [18].

As mentioned, there already exists a system which allows the analysts to visualize linked 2D and 3D views: SWIFT-3D. One of this system’s weaknesses is the fact that it isn’t the best for representing large amounts of information [7].

However, since the information that will be shown and interpreted by clients (and not the analysts) and is the result of the analysis they requested, it ends up being just a small, controlled sample (compared to the large amounts of information analysts have to go through) and as such the previous problem is avoided. This is why we think a desktop is a possible solution for viewing this information. Problems like cluttering are avoided since the participant is not overwhelmed with information (and as such a 2D visualization is possible) and it can also be paired with a 3D visualization, giving the participant a better spatial sense regarding the information s/he is seeing and interpreting. Not only does it allow for a 3D visualization combined with 2D elements, and interactions between them, but it also has very few restrictions, and it is a lot more accessible and ubiquitous than other technologies.

### 3 APPROACH

The development of this work came to be when Nokia (the world leader in infrastructure and mobile network services) proposed a challenge to develop an innovative prototype, that would display network data effective and efficiently, to be used in a department that could require such a product.

To comprehend who would benefit from this prototype and what functionalities it should have, we set out to do interviews with workers from several departments over the course of 5 months. In total, we were able to interview 10 people from three different departments. These departments were the Global Delivery Centers (or GDC), that is typically associated with companies engaged in IT consulting and services delivery business, using a support model of execution based on technology with teams that are distributed globally; the Network Planning and Optimization, responsible for
the planning and implementation of the expansion of network and also for the optimization of the network; and a third department which we can’t share too much information about for confidentiality reasons.

From the interviews we were able to conclude that while there already are tools for analysts to visualize and interact with network data, the same doesn’t apply to clients. When requesting simulations, the latter receive a report from the former with the main results from their analysis. This report doesn’t follow a template and depends on the analyst in charge of the client’s request.

Based on this, what we proposed, was a prototype that would be sent to the client (by the 3rd department worker) - alongside with the report - as a more dynamic way to display the results from the analysis made. So instead of sending the usual report and an excel file that has all the statistics and numbers - which can be a bothersome way to review the analysis’ results -, the client would be able to check the same results in a more interesting way.

Therefore, opting for a prototype that only shows the absolute essential results and information obtained in the analysis/simulation phase, not only reduces the amount of information that will be present but also narrows down the areas which will be displayed in the prototype.

Regarding the technology in which we would display this product, we concluded that a desktop would be the most appropriate. Mainly because, we are not aware of the technology that all clients possess, and desktops are one of the most accessible ways to visualize information (and according to the interviewees, the client’s preferred method to check the results). So by sending our product’s executable along with the analyst’s report, we are averting the unnecessary time-consuming tasks that come from changing from one platform to another, therefore saving the client’s precious time.

From the interviews we were also able to gather the functionalities and key performance indicators (a performance measurement that indicates to a company if a determined goal has been reached in an efficient way) that analysts considered most important for the clients to use. These were, in order of preference:

- Interacting with buildings or floors and getting their KPI values (suggested by 6 people);
- Filtering the top best/worst KPI values in a determined area (suggested by 6 people);
- Being able to visualize which cells affect a building by clicking on it (suggested by 3 people);
- Getting the top best/worst cells in a determined area (suggested by 3 people);
- Getting the id of all cells that affect a certain building (suggested by 3 people);
- Being able to take screenshots of the tool (suggested by 3 people);
- Being able to visualize what the causes for poor values of a particular KPI are (suggested by 2 people).

Having this in mind, for our prototypes we opted to display two popularly demanded KPIs by clients: Coverage (KPI value that checks whether a cell phone has a strong signal (or not) in a certain location) and Drop Rate (KPI value that represents the number of times phone calls â­‘ drop â­‘ meaning, phone calls that disconnect unwillingly), other reasons for this choice being that these are fairly different from each other (like the fact that each one has a different scale and each serves very specific purposes).

4 IMPLEMENTATION

4.1 Architecture

The development of the prototypes was done using Unity 3D and is composed of several modules which will be presented in this section.

The reason behind using Unity 3D, is first because it is a tool with a good built-in support for 2D and 3D environments. Additionally, it allows for a more comfortable development of the prototypes. There is the possibility to use assets that aid in the development, look and feel of the prototype (for example, the appearance of the UI available in Unity was not ideal for our prototype, so an asset was used in conjunction with self-made icons, to improve the overall design of the prototype, making it more aesthetic).

Additionally, it is a software that allows the implementation of functionalities with a certain depth to them but maintaining a degree of simplicity. This simplicity allows for an easy expansion of the prototype itself (adding more functionalities for example) and for a relatively easy transposition of the prototype to other platforms (like tablets, VR, etc.).

As for the modules, the first one consists of the central components of the solution and contains all the data resultant from the interactions. This corresponds to the code in the prototypes responsible for displaying and dealing with the inputs received.

This next module is the one responsible for generating the output representation of information, based on the changes made. This can be the different types of visualization (2D and 3D), the bar charts that represent the results from the filters, among others. In summation, everything the participant is able to see in the prototype.

The third module is the one responsible for receiving the relevant information to be presented in the prototypes, such as the type of KPIs (int), the values of those KPIs (float) and finally the ID of the floor/building/cell connection (string) to which the KPI is attributed to. This data is present in a JSON file that can be edited by the analyst. Before building it, the file is placed in the same folder as the project by the analyst in charge, and the information in it will then be associated with the correspondent building, floor or cell connection. If none are given, the prototype will instead have predefined test values.

Our final module is the one responsible for accepting the user’s input, meaning every interaction the participant has with the prototypes themselves.

These modules can be transposed to the Model-View-Controller software architectural pattern, where the first module corresponds to the model, the second to the view, and the third and fourth to the controller. This way, the information is inputed to the controller, which is then responsible for receiving it and converting it to commands for the model. This last one (model) retains the data from the commands and acts according to it. The resulting output from these actions is then displayed by the view (see Fig. 1).
4.2 Prototypes

Two prototypes were developed: one exclusively 2D and the other hybrid (both with 2D and 3D views). These share the same functionalities, with the exception that the latter has 2 extra buttons (to change between both views or have them at the same time).

For the development of the prototypes, several iterations were made. First, three iterations of paper prototypes were done since they led us to understand how the several functionalities should be displayed, which UI elements should be used, and allow us to test and validate several design options in a quick and easy way, with low costs [12]. Afterwards, three functional prototypes were made. All of these were shown to a focus group which reviewed and gave feedback in each iteration, aiding in the development of the prototype. Ahead, the main functionalities of the last prototype are explained.

If we take a closer look at Fig. 3 we can see in the upper left corner three buttons. The first F is the button that opens up the KPI Panel, which will allow the participant to pick its desired KPI (G). If pressed again, the KPI panel will disappear to give the participant a better visualization of the map. Below this button, are the 2D and 3D visualizations buttons (which in this picture are pressed, hence their gray color).

Now looking at the KPI panel, we can see that the Coverage KPI is selected, and as such the filtering options associated to it are available. The H area, let’s the participant choose between filtering the KPI by buildings or floors. Whenever one is pressed (as is the case of the floor button portrayed in the figure) it becomes a bit more highlighted and the building button becomes less saturated.

One thing that is fundamental to explain, before mentioning the rest of the functionalities, is the modification done to the prototype after a suggestion made by the participants of the focus group. This was the removal of both “Apply” buttons from the Coverage and Drop Rate KPIs’ panels, that was responsible for applying the changes in the filters. When playing with the interface, participants didn’t notice this button and expected the changes to be applied automatically as they were changing the filters. After figuring out how to actually apply the changes, they suggested the removal of the button. After receiving this feedback, it was, of course, applied to both prototypes. So if there are any kind of interactions with the functionalities displayed in I and J (which we will explain ahead) their results will be immediately updated.

The next functionality (represented by the I) allows the participant to choose between two filtering options. Either select all the buildings or floors (another functionality suggested in the previous iteration), or the option to sort by a select number of buildings/floors. If the latter is pressed, and only then, the area represented by the latter J appears, showing the option to choose between best or worst values, and then how many (buildings or floors) the participant desires to see. The reason behind only displaying the last area after pressing that particular checkbox, is to avoid possible confusion that could have come from having these filter options shown at the same time as the ‘All’ button. Having both checkboxes pressed is also not a possible action, because it wouldn’t make sense in this context. So if the ‘All’ checkbox if selected after the other checkbox is pressed, this last one will be unchecked and all changes in the map updated to the fulfill the last request.

In this same figure, we can see the labels that identify the visualization that is being displayed currently (letter N) and the filter options that are currently selected (letter O). This way, if the participant decides to hide the KPI panel, the applied filtering options will be visible at all times (for the eventuality that the participant forgets which filters are on).
Moving on to the Drop Rate Panel, we can see that there are some similarities with the Coverage one. The area to select the desired KPI (letter D) remains in the same place, displaying the current KPI selected, and the option to see the best or worst cell connections (letter M) follows the same design as the one for filtering the best or worst values in the coverage panel. This last one, however, is displayed at all times. If the participant decides to click on a particular building on the map, all of the cell connections linked to it will appear as well as the corresponding cells associated with them. Additionally, the checkboxes in the area represented by the letter L, allows the participant to see all the indoor or outdoor cells present in the map. Both checkboxes can also be pressed at the same time to view all cells.

In Fig. 5 we can see three buttons displayed. The screenshot button (P), the folder button (Q) to access the screenshots and the export button (R) which was a feature suggested by the participants while this last iteration was being produced. This would allow the participant to export details about the filtered data. Since the suggestion was made at a late stage its implementation was not possible due to its low priority and time constraints. It still remained in the prototype so as to understand whether or not the participants of the qualitative test could identify its purpose and if they felt it would be a useful feature.

In the lower right corner of the prototype (Fig. 6) we can see the current KPI color scale (letter S), allowing the participant to associate the value of the KPI to a color. This scale changes depending on the KPI selected (since different KPIs are measured differently). The retry and exit buttons can also be seen (T and U letters respectively). If pressed a warning panel will appear, confirming if the participant truly wants to go through this action. Lastly, we have the ascend and descend toggle (letter V) that allows the participant to change the order of the bar chart (to ascending or descending KPI values). This option is available since it is only possible to display 14 bars in this area (more would be to cluttering).

From this same area the Tooltip button was removed, however, the actual tooltips are always active. These still only show up after having the mouse hovering a button for a second. We felt the actual button wasn’t necessary since it was just an extra feature that occupies space and having its functionality without the physical button serves the same purpose. It’s still useful for beginner participants since they can obtain the information without having the need to click a button and doesn’t bother more experienced participants because it is necessary to wait for a bit to actually get the description of the button.

In Fig. 7 we can see the right panel area. The button hidden by the letter W allows the participant to show or hide this panel. However, if a certain building, floor or cell connection is clicked (with the left mouse button), this panel will also open, showing the details correspondent to the object clicked. These details will be shown in the X area. The message displayed in Fig. 7 is only present if the participant hasn’t pressed anything yet. The motive for switching from right to left mouse click to see details, was because we felt was easier for the users. Additionally, the focus group was expecting to get this information as soon as they pressed the buildings with the left mouse button when testing the interface. This was therefore altered.

The Y area is where the bar chart is displayed. As previously mentioned, the bar chart is now updated automatically (whether the participant clicks in a building/floor or decided to perform an advanced search) and the button that was previously used to create the chart was removed (Fig. 7). This decision was based on the fact that some of the people from the focus group didn’t end up clicking the button when trying out the interface, but when later shown its function, were extremely interested in it - since they thought it could improve their analysis of the data - and pleasantly surprised.

Another tip regarding detailed information was the option to, by putting a mouse over a certain object, details about it would also be presented right next to the cursor. This way, the participant doesn’t have to click on the actual object to get the information s/he wants. This can be seen in Fig. 8, represented by as a small semi-transparent purple tooltip.

Also, in order to facilitate the participant experience, we included a visual cue that consists of slightly greying out a building or floor whenever a cursor is hovering it.

As for other changes, like the interface design, only a few changes were done. The most obvious one was the addition of a terrain, with the purpose of hiding the map limitations and give a more realistic look to the map (this was done purely for guaranteeing a more aesthetically pleasing area for the people who would be performing the qualitative and usability tests).

A slightly dark and semi-transparent panel was put behind the 2D Front view, as suggested by a person from the focus group, to make it more distinguishable in relation to the 2D Top View (Fig. 2). As for the solely 2D interface, the only exception lies on the fact that the 2D and 3D buttons responsible for changing the type of visualization are not available in this one (Fig. 9). This way, we can guarantee the exact same environment to perform the tests.
Ahead we show several stills of the prototypes’ functionalities in action, like the selection of all floors in the 3D visualization (Fig. 10), filter by the 3 cell connections with the worst values (and its cells range) in Fig. 13, the gray out feature when hovering floors or buildings (Fig. 12) and the details from a cell connection (Fig. 13).

5 EVALUATION
Two different types of evaluations were performed: qualitative and quantitative.
5.1 Qualitative Evaluation

The qualitative evaluation was performed to analysts from the last department we interviewed at Nokia, which are also those who are the most familiar with network data. Since this is a small department and there weren’t many members available to test our interface we ended up with a sample of four people.

By performing this evaluation, we were able to get valuable feedback about the prototypes and suggestions for future iterations. Each participant had the freedom to test the prototypes for as long as they desired and throughout their evaluations we were able to collect some interesting feedback.

All were able to reach every functionality of the prototype without any trouble and the tester with the most experience ended up being the fastest one. However one had difficulty in finding the functionality that allowed filtering the top best/worst values (and even proposed the implementation of it for next iterations, before finding it).

Three of the participants expressed their satisfaction regarding the bar chart function since it automatically updated itself as the buildings or floors were selected and they felt it could make for an easier analysis of the data. Besides this, all reacted positively about the option to filter a number of buildings/floors/cell connections by their best/worst values was also well received, which - as expressed by them - reduced the time of search and analysis by the user. Another feature that also received praise was the option to view the cell’s range, which the participants said would be very useful for the users. This, since they would be able to immediately identify critical problems such as the incorrect positioning of the cell (having it pointed at an area with no buildings) or not having any range at all (a non-functioning cell).

The 3D visualization was also very praised, especially when the tester was looking at floor details and also the cell’s range. In the 2D visualization, two participants suggested that the Front View should have a tooltip for when the Floors were being analyzed, that would show up when the mouse would hover them, instead of only showing this information in the right details’ panel.

By the end of each evaluation, we engaged in a conversation with the participants to understand which of the prototypes was their favorite and why. All participants chose the Hybrid prototype, justifying their decision with the fact that it was overall easier to use and not as cumbersome as the 2D one (for actions like floor selections). They also stated they felt more confident using the Hybrid one and that they were able to get a better spatial image of the map. One simply justified its decision “because it is better looking than the 2D prototype and also, clients love it”.

When asked who could benefit from using this prototype and why, the participants replied “clients that request network data analysis”, “network engineers, to do the performance analysis of the network on the customer final report”, “planning and optimization network teams” and “telecommunication businesses, maybe directed o marketing people(...)” since “(...)It’s an easy way to sell solutions”. Participants also expressed that they felt the hybrid prototype would serve as a good complement to the report sent to the clients.

5.2 Quantitative Evaluation

The qualitative evaluation was performed in a quiet environment, so as to have the tester concentrated and relaxed. The number of participants who underwent the evaluation was 20 in total, of which 14 were students, with ages from 18 to 30. The remaining 6 participants were from Nokia, 4 of which with ages from 31 to 40 and 2 with ages from 41 to 50.

From the 20 users, 17 were male and 3 were female. Both groups had different backgrounds and academic degrees, but all worked daily with computers and had little to no experience with network data. Each participant tested both the exclusively 2D interface and the Hybrid one. However we also wanted to avoid biased results (since having all participants doing the same tasks twice – 2D interface first and Hybrid second – would probably result in better results the second time around, since they would already be somewhat familiarized with it). In an attempt to avoid this we counterbalanced the order of conditions; we had half the participants try the 2D interface first and then the Hybrid one, whilst the other half tried the interfaces in the inverted order.

After interacting with the prototypes, a questionnaire was given to the users, that had a set of questions. The first group consisted of personal profile questions, such as age, occupation, gender and frequency of computer usage. The next section had a set of affirmations designed to compare both interfaces in terms of complexity, the confidence of the user, easiness, etc.

To evaluate the usability of our prototypes we set out 11 tasks for the participant to do.

- **Task 1**: What’s the Coverage KPI value of the building located in the far right of the map?
- **Task 2**: Between the last building and the one located immediately to its left, which one has the biggest Coverage KPI value? State the value and the building’s respective ID.
- **Task 3**: Find out what are the 4 buildings with the best Coverage KPI values.
- **Task 4**: Identify the 2 floors with the worst Coverage KPI values.
- **Task 5**: Identify the Coverage KPI value from the third floor of a building of your choice
- **Task 6**: What’s the total number of cells in the map?
- **Task 7**: Identify how many buildings are covered by the indoor cell’s range
- **Task 8**: What’s the Drop Rate KPI value of those buildings?
- **Task 9**: Discover the 3 cell connections with the worst values and identify all buildings affected by those connections
- **Task 10**: State the id and respective causes of the 3 cell connections

To understand what prototype is the most appropriate for visualizing network data, we collected the following metrics: success rate, time spent doing task(s), critical and non-critical errors and error-free rate.

**Aggregated Results**

We started out by analysing our results as a whole (meaning that, for each metric, we calculated the average results each participant got on all tasks). Since every participant tried both prototypes, we are dealing with a two-paired sample test. After applying the
we can see that, for all but two tasks (6 and 9) the 2D prototype was done in both 2D and 3D, except for task 5, which benefits from a 3D representation because of its spatial complexity. However, with this it is possible to conclude that interestingly, the participants' performances when using the Hybrid prototype did not suffer negatively even though there were more features present in it. For these reasons, we found that it would be interesting to verify if analyzing the metrics by task would show any significant results.

### Analysis By Task

In Fig. (14) we are able to see the results of each task by time and we can see that, for all but two tasks (6 and 9) the 2D prototype performs better than the Hybrid one. These results were expected since both these tasks (finding the total number of cells and discovering 3 cell connections) that in the hybrid prototype required the participant to move the camera in order to get the results - even though the cells are, for instance, visible from any angle. In the 2D prototype, after applying the correct filter, the result would be immediately visible, hence the difference of means.

However the only tasks where participants took significantly less time doing in the Hybrid time (p<0.05) were tasks 1 and 5 (p<0.05, Z=-2.016 and Z=-3.715 respectively). This was something predictable for task 5, since it is focused on finding information about a specific floor and the 3D visualization gives the participant freedom to navigate in the map and a better spatial awareness. However, we didn’t anticipate it for task 1.

Like mentioned before, results in metrics were almost identical and as such, are not discriminated. There was, however, an exception for (again) task 5. It was possible to conclude that there was a significantly lower number of non-critical errors and a higher error-free rate in the Hybrid prototype (Z=-2.449, p=0.014) - see Fig. 15.

### Questionnaires

To analyze the results of the questionnaires filled by the participants, we used the Wilcoxon Signed-Ranked test. We used a five-point Likert Scale, where 1 corresponded to “Strongly Disagree” and 5 to “Strongly Agree”. Each question had a section for the 2D and Hybrid prototypes each, to later compare them.

From the table presented above (Fig. 16) we can verify that the mean results all favor the Hybrid prototype, even if just slightly. The standard deviation was also quite similar between prototypes and in an overall perspective never went over 1 point (except for question nr. 6).

In the ‘I though the prototype was responsive’ statement (Question 1) and the ‘I found that various functions in this system were well integrated’ statement (Question 5), we verified a significant change between prototypes (Z=2.714, p=0.007 and Z=-3.051, p=0.002, respectively), with a p-value under 0.05.

From these, we can conclude that the participants believed the Hybrid prototype was the most responsive and well-integrated from both. A possible explanation for the results obtained from the questionnaires regarding the preferences may have to do with the fact that the participants chose the Hybrid prototype simply because they favored it, although the responsiveness is the same for both prototypes. After a closer look at the remaining results we believe that there is also a tendency for participants to think the hybrid prototype is easier to use (Z=1.706, p=0.088) and feel more confident using (Z=1.667, p=0.096), although we cannot infer this with certainty (maybe with a larger sample we would be able to confirm it).

Participants were also asked to identify the tasks that they felt were more difficult and simpler to execute in each prototype (having the possibility to select more than one option). It is possible to verify that in the 2D prototype, 14 participants found the task that requires them to find the Coverage KPI value of a certain floor to be the most difficult, followed by identifying cell connection IDs (5 participants) and finding the top best/worst Coverage KPI values (2 participants). Three people didn’t feel like there was a task which was difficult to execute in this prototype.

### Shapiro-Wilk test, we verified that all data was not normally distributed. Therefore, we used the Wilcoxon Matched pairs test.

The success rate was the same for both prototypes (p=1, Z=0), as well as the number of critical errors. Both non-critical errors and the error-free rate also had a p-value over 0.8 and finally the average time spent being the lowest with a p=0.232.

We verified that the success rate mean was identical for both prototypes, although the standard deviation was slightly bigger in the hybrid one. The Hybrid prototype also had a lower mean and standard deviation than the 2D prototype (11.467 and 6.250 respectively, as opposed to 15.795 and 8.990) regarding the time spent on tasks. As for the critical errors, the mean was identical for both prototypes (1.5), although the standard deviation was bigger on the hybrid one (6.708 and 4.893). In the non-critical errors and error-free rate metric, the hybrid prototype also has slightly better results than the 2D one, with a lower mean and standard deviation on the non-critical errors (15 and 9.986, opposed to 16 and 10.462 for 2D) and a very similar, yet slightly better mean in the error-free rate metric (82.500 - Hybrid, 82 - 2D) and bigger standard deviation (11,467 and 6.250 in the hybrid one. The hybrid prototype also had a lower mean and standard deviation than the 2D prototype (11,467 and 6.250 respectively, as opposed to 15.795 and 8.990) regarding the time spent being the lowest with a p=0.232.

Therefore, we used the Wilcoxon Matched pairs test. We used a five-point Likert Scale, where 1 corresponded to "Strongly Disagree" and 5 to "Strongly Agree". Each question had a section for the 2D and Hybrid prototypes each, to later compare them.

From the table presented above (Fig. 16) we can verify that the mean results all favor the Hybrid prototype, even if just slightly. The standard deviation was also quite similar between prototypes and in an overall perspective never went over 1 point (except for question nr. 6).

In the ‘I though the prototype was responsive’ statement (Question 1) and the ‘I found that various functions in this system were well integrated’ statement (Question 5), we verified a significant change between prototypes (Z=2.714, p=0.007 and Z=-3.051, p=0.002, respectively), with a p-value under 0.05.

From these, we can conclude that the participants believed the Hybrid prototype was the most responsive and well-integrated from both. A possible explanation for the results obtained from the questionnaires regarding the preferences may have to do with the fact that the participants chose the Hybrid prototype simply because they favored it, although the responsiveness is the same for both prototypes. After a closer look at the remaining results we believe that there is also a tendency for participants to think the hybrid prototype is easier to use (Z=1.706, p=0.088) and feel more confident using (Z=1.667, p=0.096), although we cannot infer this with certainty (maybe with a larger sample we would be able to confirm it).

Participants were also asked to identify the tasks that they felt were more difficult and simpler to execute in each prototype (having the possibility to select more than one option). It is possible to verify that in the 2D prototype, 14 participants found the task that requires them to find the Coverage KPI value of a certain floor to be the most difficult, followed by identifying cell connection IDs (5 participants) and finding the top best/worst Coverage KPI values (2 participants). Three people didn’t feel like there was a task which was difficult to execute in this prototype.
When asked which prototype the participants thought was most usable, it was the Hybrid that raised the most interest, as it was appreciated that it was easier to use, with better spatial awareness, and that it was more visually appealing. Not only this, but several participants during and after had longer with the Hybrid prototype than with the 2D, which didn’t happen. Not only this, but several participants during and after the usability evaluation, stated how they enjoyed using the Hybrid prototype more, since they felt it was visually more appealing and that it was easier to get a better spatial awareness, because of the 3D View. More importantly, the analysts from Nokia, familiarized with network data and acquainted with clients, unanimously agreed that the Hybrid prototype was the one they considered best and most captivating (and since our target audience are the clients, we believe this feedback is even more relevant).

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>P-value</th>
</tr>
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<tbody>
<tr>
<td>Q1</td>
<td>4.4</td>
<td>4.85</td>
<td>0.598</td>
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<tr>
<td>Q2</td>
<td>4.1</td>
<td>4.45</td>
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<tr>
<td>Q3</td>
<td>2.1</td>
<td>2.30</td>
<td>0.641</td>
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<td>Q4</td>
<td>1.75</td>
<td>1.60</td>
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</tr>
<tr>
<td>Q5</td>
<td>4.05</td>
<td>4.60</td>
<td>0.598</td>
</tr>
<tr>
<td>Q6</td>
<td>2.00</td>
<td>1.85</td>
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</tr>
<tr>
<td>Q7</td>
<td>4.15</td>
<td>4.40</td>
<td>0.933</td>
</tr>
</tbody>
</table>

Figure 16: Analysis’ results from questionnaire

As for the Hybrid prototype, the task participants felt was most difficult was identifying cell connection IDs (7 people), followed by finding the Coverage KPI value of a specific floor (3 participants) and finding the top best/worst Coverage KPI values (1 person). In this prototype however, 10 people, from the 20 participants, stated they didn’t find any task to be difficult to execute. Regarding the simplest tasks finding the Coverage KPI value of a specific building and changing from one KPI to another were considered the easiest in the 2D prototype with 17 and 16 people each.

In the Hybrid prototype, both last tasks mention as well as Finding a KPI for a specific floor were considered the easiest, each one by 16 people. This last task stands out since it has a much better result compared to the 2D prototype (with only 4 votes instead of 16). When asked which prototype the participants thought was most efficient, 18 out of 20 responded the Hybrid one, whilst 2 preferred the exclusively 2D one. Nineteen participants also said they would use the prototypes in the future and one said it wouldn’t since it has “no use” for the user. From the results we obtained it was possible to gather that both prototypes had very similar results in terms of success rate and critical errors. As stated before, we believe this is a particularly interesting result, considering the Hybrid prototype has more features than the 2D one, which could have proven to be a more challenging task for the participants. However, this did not occur and in fact, participants did actually perform tasks quicker in the former prototype.

Additionally, participants also found the Hybrid prototype to be significantly more responsive and with better integrated functions than the 2D one. Tasks that require more meticulous spatial analysis (such as the one that required the identification of a third floor’s KPI from any building) performed significantly better in the Hybrid prototype in metrics like the time spent, the number of critical errors and error-free rate. Participants were almost immediately able to find the third floor in the hybrid prototype, but in the 2D one this proved much more difficult. This was something we expected to happen, since 3D visualization performs better in complex spatial environments than the 2D one.

For the remaining tasks (which aren’t as spatially complex as task 6) the hybrid prototype had the same performance as the 2D one, even though the former is slightly more complex than the latter. As such, it would be expected that some tasks would take longer with the hybrid prototype than with the 2D, which didn’t happen. Not only this, but several participants during and after the usability evaluation, stated how they enjoyed using the Hybrid prototype more, since they felt it was visually more appealing and that it was easier to get a better spatial awareness, because of the 3D View. More importantly, the analysts from Nokia, familiarized with network data and acquainted with clients, unanimously agreed that the Hybrid prototype was the one they considered best and most captivating (and since our target audience are the clients, we believe this feedback is even more relevant).

6 CONCLUSION

The growth and globalization of telecommunication devices have grown significantly over the years.

Naturally, the necessity to provide a quality service that tries to guarantee the best conditions for clients, has become a top priority for telecommunication companies (like phone operators).

However to do so, a constant analysis to several areas has to be done, either to ensure that problems are avoided, identify the complications behind a questionable area (i.e. an area with bad mobile service where it is later discovered that the cell providing its coverage has stopped working), or simply request a simulation to assess the outcomes for a particular situation. (i.e. what will be the drop rate on Christmas Eve, at location x).

These requests are done by companies to other telecommunication companies that specialize in network data analysis, such as Nokia, and after completing them, a report with conclusions is sent back to the former. Yet, these reports that are completed by the analyst(s) in charge of the project lack a standardization, which means that they may vary greatly depending on the person writing them.

We then proposed the development of a prototype that allows participants to easily access the results of the analysis, to serve as a hopefully more familiar tool that complements the report. Nonetheless, we had to find out what type of visualization best suits the analysis of network data, to guarantee a more efficient and effective prototype for the clients.

For this, two prototypes were developed: one strictly 2D and other with both 2D and 3D visualizations, that were later evaluated. These suffered multiple iterations and were constantly reviewed to better fill the needs that clients may have.

Qualitative and quantitative evaluations were conducted to understand both how the participants reacted to it and to retrieve important metrics. The results allow us to conclude that the Hybrid Prototype (which has the advantages from both 2D and 3D visualizations), has the same performance as the 2D prototype (even though it has a higher complexity) and is faster and more precise in tasks that require spatial complexity.

Not only this, but in both evaluations participants clearly stated their preference for this prototype over the 2D one. Results lead us to believe that a Hybrid approach is a better way to visualize network data than the strictly 2D prototype and while it can still suffer improvements, we believe it can be a valuable tool for showing information to clients’ companies in a more organized and uniform way.
7 FUTURE WORK

Although we were able to reach almost all the goals we set out to do, there were two that, unfortunately, we were unable to integrate into our prototype.

First, we have the Sit Back and Relax feature, that due to time constraints we were unable to put into our prototype. However, we still feel it could prove to be a valuable asset to the prototype since it serves as a summary of the most important results taken from the analysis that were conducted.

Second, the option to select an already selected object to deselect it, since it is a somewhat innate feature for people (something that was possible to conclude after watching the participants interactions with the prototypes).

One of the features we believe is one of most important is the option to import specific areas of maps directly in the prototype. This would be done by the analysts before sending the executable simulation took place.

Additionally, adding tooltips to the front 2D View so that details regarding building or floors are more reachable (instead of having these presented only in the right details panel). Obviously, the number of KPIs present in the prototype should be bigger, to better accommodate the clients’ requests. Moreover, we believe that the variety of information imputed by the analysts into the prototype can be expanded, so that more details can be portrayed (an example being the height of the buildings).

An interesting addition could also come from giving the participant the ability to visualize two KPIs at the same time, to compare them more easily and even be able to spot any possible unknown patterns. Finally, we also think that integrating this prototype into a tablet could be an alluring idea, since we believe it could still feel it could prove to be a valuable asset to the prototype since it serves as a summary of the most important results taken from the analysis that were conducted.

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REFERENCES


