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UCIV 4 PLANNING: A USER-CENTERED APPROACH FOR THE DESIGN OF INTERACTIVE VISUALIZATIONS TO SUPPORT URBAN AND REGIONAL PLANNING

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ABSTRACT

Decision making in the context of urban and regional planning requires communication among different stakeholders. This communication process has several barriers because of domain differences, the different nature and types of data, lack of integrated analysis tools, deficiencies in the interaction with data, and information overload. To overcome these difficulties, interactive visualizations are commonly used, and the introduction of User-Centered Design for the design of specialized interactive visualizations is an established approach to satisfy these needs. This paper presents the UCIV 4 Planning Approach to guide the design of interactive visualizations to support planning processes. This approach proposes a set of activities that help to collect relevant information about the stakeholders and their analysis tasks. Based on this information, we make suggestions of possible visualization and interaction techniques that can be applied in the design of interactive visualizations.

KEYWORDS

User-Centered Design, Analysis Task Classification, Information Visualization, Urban and Regional Planning.

1. INTRODUCTION

Interactive visualizations have been used to support urban and regional planning processes as they support effective communication and ease the comprehension and analysis of large and complex datasets (Hagen *et al*. 2009).There exist several examples of successful interactive visualizations such as Legible Cities (Chang et al. 2007), ESTAT (Robinson et al. 2005), or LIVE Singapore!

(Kloeckl et al. 2011), that support the understanding of a region's behavior. However, barriers still exist that cause communication difficulties among stakeholders. The possible reasons, why these difficulties still persist are:

- **Domain differences:** Each stakeholder wants to know different things about a region. This could result in conflicting views on development plans (Yao *et al*. 2006).
- **Nature and types of data:** There is a large amount of new data related to each stakeholder. These data have particular attributes such as temporality, accuracy, completeness, and reliability among others that makes their integration difficult (Andrienko *et al*. 2010).
- **Lack of integrated analysis tools:** Each domain has its own analysis tools. This can produce misunderstandings when trying to communicate information about a specific field to other stakeholders (Yao *et al*. 2006).
- **Missing interaction with data:** There is a need to explore a data set through interaction techniques (Buckley & Gahegan 2000). Currently, the interaction facilities are still limited.
- **Information overload:** There is a trend to overload visualizations. Traditional visualizations of data layers allow users to display a large amount of data but at the cost of comprehensibility of information (Chang *et al*. 2007).

In order to overcome these barriers, it is necessary to provide a richer visual analysis environment. This project focuses on the design of interactive visualizations that support stakeholders' analysis tasks. In this context, User-Centered Design (UCD) is a well-known approach to guide the development of interactive visualizations (Cartwright *et al*. 2004), (MacEachren & Kraak 2001). We propose a user-centered approach based on three phases: analysis, design, and implementation. Each of these phases has a set of activities including a feedback activity whose purpose is to perform early evaluations with users. Our approach has a strong emphasis on the analysis task description, which is the basis for making recommendations about the visual representation and the interaction techniques. Our contribution consists of a structured process to guide the design of interactive visualizations to support urban and regional planning. This process takes into account the analysis tasks, knowledge-base, and other guidelines found in the literature in order to suggest and select appropriate visualization and interaction techniques. The adaptation of UCD approaches to the planning field can facilitate the understanding and communication of urban and regional phenomena among stakeholders.

2. RELATED WORK

User-centered design (UCD) is a methodology in which users, their wants and needs, requirements, and tasks, are the driving force in the development of a product (Preece *et al*. 2002). The purpose is to make products more usable, in other words, “The product should suit the user, rather than making the user suit the product” (Courage & Baxter 2005).

A large number of visualization projects that use UCD approaches are based on the definition of ISO 13407:1999 (ISO 1999). This standard called “Human-Centred Processes for Interactive Systems” provides general guidelines for introducing a UCD approach within a project. It describes an iterative process that involves at least four iterative stages before getting into the final design. Poppe and Elzakker (Poppe) present an adaptation of the ISO 13407:1999 cycle diagram for UCD approaches. According to ISO 13407:1999 (ISO 1999), the employment of UCD processes has several benefits for products and users: Products become easier to understand and use, products can improve user satisfaction, users can increase their productivity, and product quality is enhanced.

UCD approaches provide designers with a structured way of developing products that suit user needs. The main principles comprised in this view are: an early focus on understanding the user and the context of use, empirical testing and evaluation of the product design by representative users, and an iterative design process of four stages (Poppe & Elzakker 2006).

Applications and studies about UCD approaches in the field of geovisualization have been made in order to address the need for more useful and usable visualizations. Lloyd and Dykes (Lloyd) mention that there is a knowledge gap between users and designers when trying to customize general visualization applications to a specific field, in this case, geovisualization. They present a long-term case study where they tested a group of UCD methods in different contexts to find out when a method is suitable for a certain purpose and when not.

Wassink *et al*. (Wassink) propose a three phase process for the design of interactive visualizations. These phases are: early envisioning phase, global specification phase, and detailed specification phase. Each phase can contain more than one iteration and each iteration consists of three activities: analysis, design, and evaluation where the authors suggest some methods to guide the design process.

Other projects such as the ones presented by Carneiro (2008), Freitas *et al*. (Freitas Prieto, D., Zeckzer, D., and Hernández, J.T., 2013, Case Study Bogota 21 – Designing Interactive Visualizations to Support Urban and Regional Planning, *EuroRV3: EuroVis Workshop on Reproducibility, Verification, and Validation in Visualization*, Leipzig, Germany.

), Robinson *et al*. (Robinson), and Roth *et al*. (Roth) give insights about the advantages of the use of UCD, as for example, the engagement of stakeholders with the developed visualization tools, the finding of "undreamed of" requirements (Robertson 2001) associated with the displayed data, and the enhancement of understanding the problem domain.

3. UCIV 4 PLANNING APPROACH

UCIV 4 Planning is a user-centered approach for the design of interactive visualizations to support urban and regional planning processes. It is based on the detailed description of the stakeholders' analysis tasks. This includes a description of a guiding question (what do the stakeholders need to know about the region?), the data that is required to answer the guiding question, and which stakeholders of other domains have an influence on the answer.

Figure 1 illustrates the general concept of the proposed approach. It is a cyclic development model consisting of three phases: analysis, design, and implementation. Each phase uses the knowledge-base of urban and regional planning and is guided by analysis tasks. Besides, each phase includes a set of activities whose results are assessed through a feedback activity that determines if it is necessary to repeat the phase or if we can continue with the next phase. Below, we describe each of the phases and its activities.

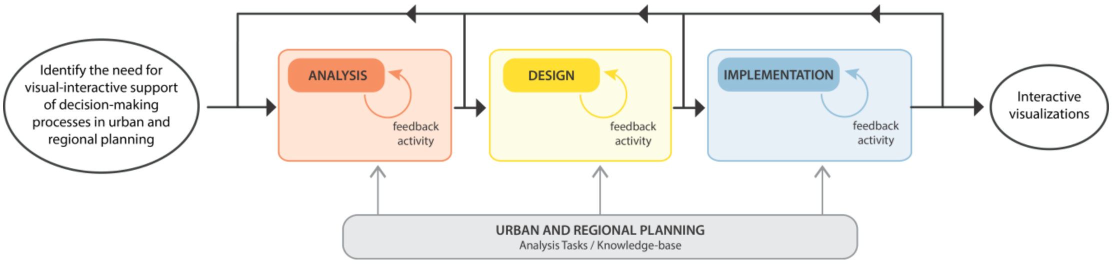

Figure 1. UCIV 4 Planning Concept

3.1 Phase 1: Analysis

The goal of Phase 1 is to learn about the stakeholders. Two activities are suggested in order to gather and classify analysis tasks. A third activity (feedback activity) is introduced to evaluate the results of the previous activities together with the stakeholders. The output of this phase is an analysis tasks inventory.

3.1.1 Activity One

Activity One consists of three sub-activities that aim to gather essential information about the stakeholders and their analysis tasks:

1. Identification of the stakeholder profiles: to identify the stakeholder profiles, a specific questionnaire was designed to determine the domain of each stakeholder, their experience, and particular planning scenarios they have worked on.
2. Determine context of interactive visualizations: by observing a planning session, it is possible to gain knowledge about when interactive visualizations are used as well as to identify opportunities to improve planning processes through the use of visualization tools.
3. Determine analysis tasks: the stakeholders are interviewed to extract the guiding questions that will drive the development of the interactive visualizations. The core question of this interview is: what do you (as a stakeholder) need to know about the region? The answer to these questions will be used to set out specific analysis tasks. In addition to the core question, the stakeholders are asked to provide a list of the possible data needed to fulfill the analysis task.

3.1.2 Activity Two

Activity Two is focused on the classification of analysis tasks. We propose a classification method which enables to infer visualization and interaction recommendations. This classification method consists of three parts:

1. Analysis task type: Pinnel *et al.* (1999) suggest a task classification based on the cognitive processing activities required to perform each task. It provides a high level classification containing a wide range of tasks that we adapted to the urban and regional planning domain. Table 1 shows the possible categories for classifying analysis tasks.
2. Visual operations: Once the analysis task type is determined, we proceed to find the possible visual operations that can be associated with each type of analysis task. A visual operation can be defined as the visual result of applying certain transformations to a set of objects. According to Wehrend and Lewis (1990), this transformation is directly related to the user

tasks. These authors present a taxonomy that includes the following visual operations: identify, locate, distinguish, categorize, cluster, distribution, rank, compare, associate, and correlate. We will use only *identify, locate, associate*, and *compare* operations as they seem to be most appropriate for analyzing geospatial data (Ogao and Kraak 2002). To link analysis task types and visual operations we created the matrix presented in Table 1, where analysis task types are related to one or more visual operations.

Table 1. Analysis Tasks Taxonomy. Analysis Task Type and Description are adapted from Pinnel *et al.* (1999), while we combined those with the visual operations.

		Visual Operation			
Analysis Task Type	**Description**	**Identify**	**Locate**	**Associate**	**Compare**
Spatial determination	Identify the location where a specific urban phenomenon takes place.	X	X		
Comparison of values or attributes	Identify differences between attributes or values of urban elements.				X
Distinguishing between alternatives	Highlight differences between two or more urban interventions or stages in time.				X
Locating optima	Find the best location for an urban element in the urban system.		X		X
Determining trends	Discover patterns in the evolution of an urban phenomenon.			X	X
Relations between attributes	Understand and interpret relations between attributes of different urban elements.			X	X
Aggregation of information	Observe the attributes of urban elements in a higher level.			X	
Qualitative information	Establish comparative measures for qualitative attributes of urban elements.			X	X
Quantitative information	Identify patterns of change of quantitative attributes of an urban element.			X	X
Description	Observe the behavior of an urban phenomenon in a specific context.	X	X	X	X

3. Interaction operations: In addition to visual operations, we must also consider interaction operations to complement visual operations. Yi *et al.* (2007) propose seven categories to classify interaction techniques commonly used in Information Visualization. These categories are:
   - Select: mark something as interesting
   - Explore: show me something else
   - Reconfigure: show me a different arrangement
   - Encode: show me a different representation

- Abstract/Elaborate: show me more or less detail
- Filter: show me something conditionally
- Connect: show me related items

For each category, there is a set of recommended interaction techniques that can be integrated into our interactive visualization. At the end of these two activities, the descriptions of the analysis tasks, its corresponding classification, and the raw data needed should be clear. This will enable developers of the interactive visualizations to understand the interests of the different stakeholders as well as to obtain a first guide of what to do in terms of visualization and interaction operations.

3.1.3 Feedback Activity: Focus Group

The feedback activity consists of a focus group session (Preece *et al.* 2002) whose purpose is to share the results of the two previous activities with the stakeholders. The expected output of this activity is a set of analysis tasks with its corresponding classification (task type, visual operations, and interaction operations) approved by the stakeholders in order to guarantee that the intention of the original analysis tasks is preserved. In case the stakeholders do not approve the proposed analysis task description, a complete iteration of Phase 1 should be considered. However, if the stakeholders do not approve the proposed classification and related data, only a new iteration of Activity 2 and 3 should be considered.

3.2 Phase 2: Design

Phase 2 examines the criteria for selecting visual representations and interaction techniques according to the analysis task type. The first two activities focus on the search of design guidelines from involved domains and visual perception literature. The feedback activity consists of a Participatory Design session based on the evaluation of a paper prototype. The aim is to evaluate the appropriateness of the selected guidelines before proceeding with the implementation of the interactive visualizations.

3.2.1 Activity One

An important aspect to consider for the design of interactive visualizations is the stakeholders' knowledge-base. It is necessary to apply guidelines, standards, and rules for the display of spatial information in all involved domains.

For this activity, we suggest a literature review and interviews with the stakeholders so as to know, if there are specific standards that apply to a specific analysis task. The American Planning Association - APA provides general standards for urban and regional planning. Among these are those highlighted in the books “Planning and Urban Design Standards” (American Planning Association 2006) or the “Land Based Classification Standard –LBCS” document (American Planning Association 1996).

In addition to knowledge-base guidelines, several human factors aspects such as perception and cognition should also be considered (Tory and Möller 2004). In the specific context of urban and regional planning, it is important to strengthen the link between the stakeholders’ knowledge-base and the theories of perception and cognition.

From the visualization perspective, the appropriate use of visual attributes for encoding certain data types has to be considered. For example, Ware (2004) describes the operation of the visual apparatus as a function of perception. Two examples of Ware's guidelines referring to the use of color are:

- “The use of gray-scales colors is not a particularly good method for coding data”.
- “For ordinal values to be correctly and rapidly interpreted, it is important that the color sequence increases monotonically with respect to one or more of the color opponent channels”.

On the other hand, Mackinlay (1986) in his effort to automate the design of visual representations proposes a ranking of appropriateness for the use of visual attributes for encoding quantitative, ordinal, and nominal data (Mackinlay's ranking). From the interaction perspective, Yi *et al.* (2007) present an inventory of possible interaction techniques associated with each interaction operation.

3.2.2 Activity Two

Activity Two consists of designing and prototyping interactive visualizations based on the guidelines found in the previous activity. The input for this activity is the detailed description of one analysis tasks and its related knowledge-base. This description should include:

- Analysis task classification: task type, visual operations, and interaction operations
- Raw data description: data types for the required data to perform the task
- Knowledge-base related to the task: standards or guidelines for the visual representation

The prototypes developed can have different resolutions: Low-fidelity, such as sketches for presenting possible representations or paper prototypes (Snyder 2001) for modeling interaction; or hi-fidelity prototypes such as Processing (Reas and Fry 2007) prototypes with some of the visualization and interaction aspects included. For the first iteration, we recommend paper prototypes as they are fast to develop and as they allow making fast changes on the fly. Further iterations can include more advanced prototypes using larger amounts of data.

3.2.3 Feedback Activity: Participatory Design session using Paper Prototypes

In order to assess the prototypes, we propose a Participatory Design session using paper prototypes (Osman and Baharin 2009). This test aims at evaluating part of the functionality of the interactive visualizations as well as the visual representations with the stakeholders. A facilitator who knows the behavior of the proposed interactive visualization simulates the response of the system when a user (in this case a stakeholder) performs a certain action on the interface. All the responses considered for the interactive visualization should be part of the prototype so the users can see the reactions to their actions. During this session, the stakeholders are invited to comment about the visual representation of the data and the selected interaction techniques in order to improve the prototypes for a new iteration, if necessary.

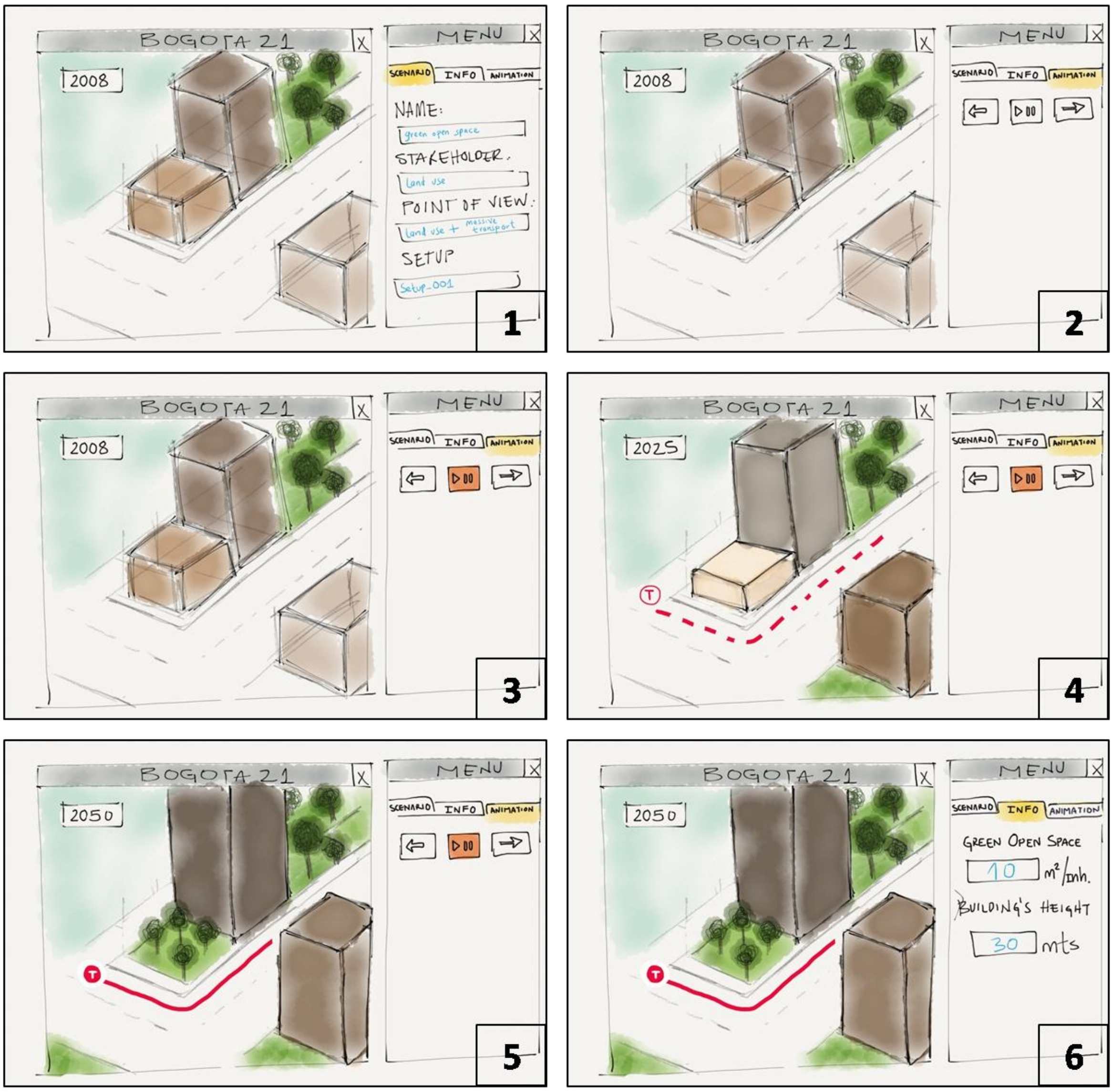

Figure 2. Paper prototype example.

Example: Suppose you want to develop an interactive visualization to support an analysis task that aims at analyzing the recovery of green open spaces in a city from 2008 to 2050. The images presented in Figure 2 show an example of the possible interactions that stakeholders can perform during the development of this analysis task. Each image shows the result of the interaction performed in the previous state.

1) The user selects the “scenario” tab in the menu panel: information about the configuration of the scenario is displayed.
2) The user selects the “animation” tab in the menu panel: animation buttons appear in the menu.
3) The user presses the “play/pause” button: the animation starts.
4) The image changes and shows the state of the scenario for the year 2025.
5) The image changes and shows the state of the scenario for the year 2050.
6) The user pauses the animation and selects the “info” tab: information about the state of the scenario for the year 2050 is displayed.

At the end of the participatory design session, stakeholders will tell you what they think about your design, what is not clear, and what should be changed.

3.3 Phase 3: Implementation

Phase 3 incorporates the selected visual representations and interaction techniques into interactive visualizations. The output of this activity is a set of interactive visualizations assessed with the stakeholders through a usability test. These interactive visualizations support all analysis tasks identified in Phase 1.

3.3.1 Activity One

Activity One comprises the processing of the Participatory Design session (PD session) results in terms of possible visual and interaction misunderstandings. As the stakeholders had a simulated experience during the PD session, they could point out particular aspects of the visualization and interaction that can cause troubles when performing the analysis tasks. Among the possible misunderstandings that can occur there are:

- Conflicting knowledge-base guidelines.
- Conflicting perception and cognition guidelines.
- Conflicting interaction techniques for selecting, exploring, reconfiguring, encoding, abstracting, filtering or connecting data.
- Conflict between visualization and interaction techniques (e.g., use the same color for highlighting selected features and for encoding data).

The expected output for this activity is a summary of the misunderstandings identified by the stakeholders and the solutions they suggested.

3.3.2 Activity Two

The objective of Activity Two is to define how visual representations and interaction techniques are going to be integrated into the interactive visualization. The decision of what technology to use should be based on the results of the previous phase (analysis tasks, visual operations, and interaction operations) and a review of possible technologies that support these requirements.

3.3.3 Feedback Activity: Usability Test

We propose a usability test to evaluate the interactive visualizations that we designed regarding the following usability criteria described by Tullis and Albert (2008):

- Effectiveness: Being able to complete a task.
- Efficiency: The amount of effort required to complete the task.
- Satisfaction: The degree to which the user was happy with his or her experience while performing the task.

For this activity, we propose a task-based evaluation. For each interactive visualization to evaluate, we will have a set of research questions and a set of specific tasks that the participant of the test should perform. These tasks are designed to find answers to the research questions. We propose to classify the participants of the test among the following categories:

- Faculty members (researchers)
- External consultants
- Transportation experts
- Land use experts
- Other domain experts
- Local government representatives
- Regional government representatives

For each category of participants, there is a different questionnaire describing the tasks that they should achieve during the test. The questionnaires have the same set of tasks but they are written using a language adapted to and understandable for each group of participants. This strategy helps to reduce the time and the effort spent by participants trying to understand what they are asked to do and as a result this helps to keep participant's focus on performing the tasks.

A series of metrics is associated with each criterion. For example, *effectiveness* can be measured using a task success metric or the error count; *efficiency* can be measured using a time-on-task metric or learnability metrics; and *satisfaction* can be measured using self-reported metrics. Table 2 presents a set of metrics that can be used to measure the mentioned criteria.

Table 2. Evaluation metrics.

Metric	**Description**
Task success	The participant completed the task
Time-on-task	Time spent completing the task
Level of success	Complete success With assistance Without assistance
	Partial success With assistance Without assistance
	Failure
	Participant thought it was complete
	Participant gave up
Trials and errors	How many errors did the participant commit during the task
Learnability	Time-on-task was improved compared to previous executed task
Likert scale	1.Strongly disagree 2.Disagree 3.Neither agree or disagree 4.Agree 5.Strongly agree
Semantic Differential Scales	Difficult – Easy Confusing – Very clear

After analyzing the results of the usability test, starting a new cycle should be considered:

- Starting from Phase 1, if there are misunderstandings related to the purpose of the analysis tasks, or
- Starting from Phase 2, if there are issues with the design of the visual representation or interaction, or
- Starting from Phase 3, if the implementation has to be improved.

This decision will depend largely on the evaluation results and the acceptance criteria determined by the stakeholders.

4. CONCLUSION

We have comprised and adapted relevant methods and techniques from User-Centered Design in a structured process in order to guide the design of interactive visualizations to support urban and regional planning. The use of UCIV 4 Planning Approach promotes the documentation of analysis tasks and knowledgebase guidelines that are dispersed in the literature. This not only can improve the quality of the design and production of interactive visualizations but also can help to gain a better understanding of the tasks involved in urban and regional planning.

There is potential for applying the UCIV 4 Planning approach to other fields as this approach is general enough to be extended and adjusted to other domains. In that case, the classification process presented in Phase 1 - Activity Two should be redefined based on the particular knowledge of the field.

We also found some issues that must be considered when using the approach. It is necessary to clarify the role of the stakeholders during the design process. The stakeholders are invited to participate in the feedback activities of each phase. They can comment and do suggestions about the material presented to them, but:

- How are they involved in the design process?
- Can they "change" design decisions about the interactive visualization or do they only point out their opinion?
- Do they have a role as evaluators or as co-designers?

The selection of the type of role for each stakeholder has a high impact on the acceptance of the final interactive visualizations.

By using the proposed approach it is possible to obtain visualization and interaction recommendations that support a specific analysis task. Then, depending on the analysis task type, visual and interaction operators can be used to select specific visualization and interaction techniques. The challenge is in how to produce interactive visualizations that support multiple analysis tasks avoiding the development of highly specialized tools only usable for expert trained users.

We applied the UCIV 4 Planning approach in a project. The results of this case study are presented in the paper "Using User-Centered Techniques for the Design and Evaluation of Interactive Visualizations to Support Urban and Regional Planning: Case Study Bogotá 21" (Fernández Prieto, *et al.* 2013). Future work includes the implementation of the approach in different application areas, for example, in the analysis of medical imaging or in software visualization, and lastly the formal evaluation of the interactive visualization produced by using our approach.

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