Campus Information-and-knowledge Modeling: Embedding Multidisciplinary Knowledge into a Design Environment for University Campus Planning

Paula Gómez Zamora and Matthew Swarts
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This article gives an overview of our research approach in collecting specific information and multidisciplinary knowledge with the aim of integrating them into a model for the planning of a university, supported by a design environment. Our goal is to develop a strategy for modeling raw information and expert knowledge for the Georgia Tech Campus. This research was divided into three stages: First, we identified a variety of written sources of information for campus planning, extracting and distinguishing raw information from disciplinary knowledge. Second, we selected the elicitation methods to gather knowledge directly from experts, with the objective of performing qualitative assessments—effectiveness, efficiency, and satisfaction—of certain features of the Georgia Tech Campus. Third, we interpreted the information and knowledge obtained and structured them into Bloom’s taxonomy of factual, conceptual, procedural and meta-cognitive, to define the specific modeling implementation strategies. Currently, we are implementing a Campus Landscape Information Modeling Tabletop in two phases. First, constructing an information-model based on raster and vector models that represent land types and landscape elements respectively, to perform quantitative assessments of campus possible scenarios. Second, embedding knowledge and qualitative aspects into a knowledge-model. The long-term goal is to include quantitative as well as qualitative aspects into a computational model, to support informed and balanced design decisions for university campus planning. This paper specifically focuses on the construction of the knowledge-model for Georgia Tech Landscape planning, its structure, its content, as well as the elicitation methods used to collect it.
I. INTRODUCTION

Designing and planning a university campus is very complex and detailed since it gathers a variety of disciplines for collaboration, to ultimately agree on a single plan. Throughout the design process, a high number of decisions have to be made by the experts in each field—landscape designers, architects, campus facility managers, managers of colleges, and services, among others—accomplishing a number of diverse objectives while being limited by a variety of constraints. The difficulty is on conveying every perspective into a unique plan. In this scenario, supporting collaboration among experts is essential to explicitly interchange views bringing specific goals, constraints and priorities into a common design space. With this goal in mind, we have developed a strategy for collecting and modeling raw information as well as expert knowledge into a single platform: Campus Information-and-knowledge Modeling. This research progressed into two parallel but integrated developments: Landscape and building models. This paper will focus on the first one.

The current trends in computer-aided design mostly focus on storing a variety of projects’ information, to run analysis and evaluations of different aspects of the project, all quantifiable. Their goal is to obtain specific information to make decisions about design strategies or changes in a timely and resource efficient manner. For architecture and city planning, the two well-known information model frameworks are Building Information Modeling (BIM) and Geographic Information Systems (GIS). While BIM supports detailed modeling and evaluation at the building scale, GIS supports planning and evaluation at the urban scale. On the one hand, BIM is an integrated model that is capable of storing geometric information about buildings, their attributes, and their relations to one another. BIM provides integration of such information by mapping non-spatial information into the model and allowing one to run a series of analyses, such as cost, energy, lighting, etc. [1]. On the other hand, GIS is an integrated system that allows capturing, storing, retrieval, checking, integrating, manipulating, and analyzing spatial data [2]. BIM and GIS approached two different scales. To complement both approaches, Campus Information-and-knowledge Modeling (CIKM) is designed as an intermediate scale model that stations between architecture and urban scales, including buildings as well as landscape, additionally to other intermediate aspects that intrinsically belong to campus scale, such as parking lots, bike routes, recycling and trash networks, etc.

Earlier efforts focused on addressing projects at the landscape design scale. Some of them are simply focused on interactive collaboration, using landscape design as content to develop interactive maps, however, none of them have approached the campus scale including buildings. LANDSVIEW [3] and SELES [4] focus on forests. The first one visualizes a raster model of forest succession and disturbance (LANDIS) through spatial and temporal...
scales; while the second build and run models of landscape dynamics, combining event simulation with a spatial database. Smart Plan developed by Sasaki [5], focuses on the intermediate landscape scale, including building use in their interactive models. Software companies such as Autodesk [6] with DreamScape by 3DS Max, focused on rendering realistic landscapes, LANDCADD, Eagle point, and Land F/X, on the design of irrigation systems. Also, plug-ins such as Carbon Scatter (by 3DS Max) helps designers to manage populations, such as large distribution of trees. KeyPAVING and Siteworks [6] are grading tools to model pads, parking lots, streets, sidewalks and more. Vectorworks Landmark [7] allows to set trees, sun, site buildings, as well as plant lists, importing PDFs and DWGs. Landmark also allows export formats such as images and databases, as well as 2D and 3D representations. Also, there are some efforts on interaction using large screen maps [8, 10], negotiation of stakeholders using virtual reality and physical interaction for terrain manipulation [9].

Our proposal is that Campus Information and Knowledge Modeling integrates both building and geographic scales into a campus scale model [11]. CIKM stores information about spatial as well as non-spatial features, comprehensively analyzes spatial and non-spatial data, such as cost and goals, to finally integrate the spatiotemporal-referenced information, by scenario structure, displaying it as a spatial and temporal representations. Georgia Tech’s CIKM is composed of building and landscape information combined into one design space [12,13]. However, independent of the technological improvements that could be applied to our project, our main goal is to integrate information and knowledge, and propose a method to capture specific expert knowledge from landscape designers, and include it in the process of design and implementation of the CIM tool. The main objective of this method is to construct the knowledge taxonomy by Knowledge Type, Strategies, and Structures (table 1), which can be stored and accessed digitally.

2. AN INTERACTIVE TABLETOP FOR LANDSCAPE DESIGN

Campus Landscape information Modeling –CLIM tool– was developed with the purpose of supporting direct collaboration among different disciplines by accessing real time information and evaluating landscape projects [14, 15]. The main structure of the model allows storage and retrieval of alternative designs as projects or scenarios. A project is defined by three variables: the area to be modified, the initial date, and duration of the project in a timeline. It could be stored by name, and has a list of goals and constraints, classified by owner. For example, a parking building’s owner is Parking and Transportation Services, which has their own budget and managers. However, the parking serves the Student Center.
Scenario is a collection of projects, which may have different clients or stakeholders, but which collectively have specific goals, locations, or scheduling in common. For example, a tennis fields on top of a parking structure. They are part of the same physical project, yet support global goal: Increasing the amount of green spaces in core areas of campus. Budgets, however, come from different departments, and have different interests, goals and constraints. By taking advantage of the data storage system, we proposed a scenario comparison toolkit to find the best alternative.

3. CMIK: CAMPUS MODELING OF INFORMATION AND KNOWLEDGE

CMIK’s two fundamental models –Information and knowledge models– differentiate themselves by the complexity of their construction. While the information model refers to the integration of geometric representation of objects and their attributes, the knowledge model refers to the variables, constraints, goals, operations, and their relationships to construct quantitative and qualitative evaluations, in order to specify semantic meanings. These two models organize frameworks for data and knowledge, for exploration and understanding of decisions, and for comparison across systems. The top-view of the campus, which is displayed on the tabletop, is constructed on top of two types of information model views: A raster model representation and a vector representation (see figure 1). Raster models represent land use types, while vector models represent land elements such as trees from the tree inventory carried out in 2012 and are continually updated. Assessment results, which are visualized on the dashboard, integrate literal information and the expert knowledge from sources, to convey the relationships, dependencies, and conditionals for decision-making. The user interface features –such as the layout, icons, and commands– are constructed on top of the aforementioned information models and knowledge model. In the following section, we describe in detail the information models and the knowledge models on which our CLIM is built.

Knowledge models are essentially connected with information models, and more over, they are built on top of them. Without information models it is impossible to build knowledge models. However, the main difference between them is that information or data could be literally translated into models –such as raster and vector point models—, and knowledge comes from experts’ experiences, which sometimes has been translated into several sources such as manuals and representations. Another type of knowledge, however, is directly applied from experts’ minds to a project in real time workshops and meetings. In this project, we have included five fundamental sources of landscape knowledge: Facilities Inventory and Classification Manual (FICM) [16], Landscape Master Plan document.
4. FROM INFORMATION TO KNOWLEDGE MODELS

The areas of architecture, landscape design and urban design have been adapting Computer Science approaches of data and information managing for the past decades. Two well-known examples were reviewed in the previous section: BIM and GIS, which first were focused on the data processing –filtering it, understanding its relations, and obtaining object properties, and then focused on information organization, making the data useful. Information, on the one hand, is both factual and numeric data that is organized intelligently, and can be analyzed or summarized with a purpose [18]. After a cleanup process, analysis to make relevant observations, and organization in an understandable format, the perceived value among users is increased, which is determined by its importance in the context of decision-making, or to its outcome. Accurate, timely and relevant information help us to reduce costs, save time, and improves decision-making. Knowledge, on the other hand, is “information combined with experience, context, interpretation and reflection” [19].

Recently, the interest has shifted toward Knowledge Management, focusing on the contextual knowledge and prediction estimation capabilities for decision making, and knowledge reuse, including integrated knowledge, understandable and actionable [20], toward establishing and achieving goals. Different organizations have realized that knowledge is one of their most important assets, therefore, storing and managing it means to achieve organization’s effectiveness and efficiency, that leads to competitiveness [21].

Managing knowledge, however, requires an interdisciplinary approach and...
technological and human resources, firstly to collect it and store it, constructing an “organizational memory”, for communication among users and reuse in context [20]. For several decades, the focus of Knowledge-based system Engineering has been on the development of methodological approaches to operationalize experts’ knowledge, developing appropriate methods, languages and tools for Knowledge-based systems (KBS) [21, 22]. This organizational memory is a combination of unstructured and structured knowledge of diverse sources.

5. KNOWLEDGE SOURCES

Campus Information-and-knowledge Modeling (CIKM) was conceived for a specific university campus: the Georgia Tech campus. Both general and specific sources of information and knowledge were utilized to construct these two fundamental models upon which CIKM is based. The information model is based on raw data, such as land use, tree inventory, parking inventory, lighting inventory, water systems, etc., that was extracted from global and local written sources as well as specific samples. The knowledge model is constructed from expert and user knowledge, which was extracted from both written and non-written sources. For the latest, we used four elicitation techniques to gather knowledge: Existing documentation, Observation of experts collaborating on a specific case study, analysis of tasks of the specific case study, and interviews with experts and users [23].

Written sources and elicitation techniques

We used five main sources to extract expert knowledge about campus design. The basal knowledge came from a manual about educational facilities in general, FICM Manual, and then from Campus Master Plan and Strategic Vision and Plan documents, which are specific to the campus. Once the documents were processed and the knowledge was classified, we continued including experts perspective form a City Planning Studio. Intermittently, we ran our project structure through a specific and real-world case for a campus renovation for 2015, lead by the Space and Management group. From the Campus Master Plan and Strategic Vision documents we recognized the main goals and constructed a principal causal model. This model helped us to understand what variables influence the accomplishment of main goals and secondary objectives. As we will review, these goals are both quantitative and qualitative; therefore we developed a strategy to include them on our causal model. We verified the model through reviews with planning and design experts.
Postsecondary Education Facilities Inventory and Classification Manual (FICM, 2006) by The National Center for Education Statistics (NCES) is a manual that provides the concepts and definitions for “reporting on the major components of postsecondary physical facilities: Namely, buildings and the use of space within those buildings”, including key organizing principles, purposes, and components of a facilities inventory system, guidance for reporting and analysis, building definitions, measurements and data elements, room use and the extensive room use coding structure [16]. We used this space classification to construct the UML Diagram [24] in which the tool lay on. It includes the objects and variables, from landscape elements, such as land use type, to algorithms for evaluations such as gross areas, costs, and quality conditions.

Campus Master Plan

The Campus Master Plan for Georgia Tech, revised in 2011 [17], compiles the design practices and guidelines for a university campus design. The University’s main goal is to build a “livable, sustainable, and beautiful campus”, overreaching three goals: “1) Develop an integrated, ecologically based landscape and open space system that helps our university to achieve its goal of environmental sustainability. 2) Develop a landscape that enhances the living, working, learning environment of the Institute. 3) Develop a landscape that unifies the campus and gives it a distinct sense of place and expresses the identity of our university.

Specific objectives for Campus Planning are related to Energy and Atmosphere, Water, Vegetation, and Human Design [17]. We classified specific objectives into quantitative and qualitative objectives. Quantitative objectives such as “Increase campus tree cover to 55%”, “Increase campus coverage by woodlands to 22%” or “reduce storm water discharge to the Atlanta sewer systems by 50% over 2003 levels” for example. Other qualitative objectives, that are a challenge to measure by any algorithm, are “Create campus legibility/orientation” and “Unify the campus and create a sense of place”, for example.

City Planning Studio

Projects on one university boundary developed on a city planning studio are our reference to understand the design process for landscape designers. The information that emerged from these projects served as examples of what is important in making design decisions for the campus scale. An example is how pedestrian movement and transportation systems co-relate to street designs, including sidewalks, street trees, streets lighting, transportation systems, crossing, and signalize. From the pool of alternatives proposed, we understood that there are several solutions to one specific design problem.
We took the case of street section, and defined an approach of a parametric solution for it. It maintains the width through modification of entities along the street. The following are a set of four common street section templates that emerged from our observations:

- Sidewalk / buffer + tree / bike / thru / thru / median / left turn lane ||
- Sidewalk / buffer / bike / thru-street car / thru / thru / median ||
- Sidewalk / buffer / bike-bus / thru / thru / median ||
- Sidewalk / buffer / bike / [Parking or Bus pull-off or Right-turn] / thru / thru / median ||

Case Study and Interviews

We used a real campus renovation scenario planned for 2015 on the northwest area of campus. The site covers nearly 20% of the campus and includes renovation, demolition and construction of housing buildings, parking buildings and parking lots, dining services, maintenance services, and landscaping between buildings. We manually ran the knowledge structure and tool structure through this specific project to find the gaps and to validate our approach. At this level, we introduced structural changes such as the data structure of: A project, a set of projects, a scenario, and their comparison on a timeline. We added the schedule attribute to the projects and sets of projects, as well as the constraints of maintaining certain services along the construction process. In this specific case, the main constraint was to maintain the number of parking spots during the renovation process. The constraints on the number of beds for residential buildings change depending upon the season. During the summer semester for example, the number of beds needed are less than in the spring or fall semesters.

The qualitative goals such as “Create campus legibility/orientation” and “Unify the campus and create a Sense of Place” were mostly based on quantitative inputs, as the information models prescribe, so they did not pull as much weight in decision making. With the intent of incorporating qualitative knowledge into our models, we defined a usability model, which included all users of campus – including students, academic, administrative, and visitors. The main goal, which is the focus of this paper, was to structure the knowledge in a general way that could be replicable and not simply anecdotal. For this reason, we based our structure on Bloom’s adapted knowledge taxonomy.

6. KNOWLEDGE TAXONOMY

We structured the extracted knowledge into four categories to better understand its impact on the knowledge-based modeling strategy. We used a

* || = symmetric street section
structure of the knowledge dimension of the Bloom’s revised taxonomy of Factual, Conceptual, Procedural, and Meta-Cognitive Knowledge [25] as a base for the structure of our knowledge-based model, using four strategies respectively: Specifications of Details; Categories, Models, and Structures; Algorithms and Procedures; and Strategies (table 1) [13].

<table>
<thead>
<tr>
<th>Knowledge Dimension</th>
<th>Knowledge Strategies</th>
<th>Knowledge Structure</th>
<th>Example</th>
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</thead>
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<tr>
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<td>· Tree Types · Tree location · Land Use</td>
<td>FCIM Case Study</td>
</tr>
<tr>
<td>Conceptual knowledge</td>
<td>Categories, Models, and Structures</td>
<td>· Categories Structure · Groups of Categories · Layers · Timeline</td>
<td>· Layers · Zones · Projects · Scenarios</td>
<td>FCIM Case Study</td>
</tr>
<tr>
<td>Procedural knowledge</td>
<td>Algorithms and Procedures</td>
<td>· Commands · Variables · Parameters · Constraints · Evaluations · Assessments · Design Guidelines</td>
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</tr>
<tr>
<td>Meta-cognitive knowledge</td>
<td>Design strategies Context and Conditions</td>
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<td>· Time representation · Scenarios · Goals · Structures · Strategies</td>
<td>Case Study CMPU</td>
</tr>
</tbody>
</table>

6.1 Factual Knowledge

Factual Knowledge refers to the basic elements within a discipline [25]. It emerges from the combination of raw information and expert knowledge that modifies that information by specifying graphic representations, such as colors and representation of elements. For example, the raster model is based on land use information extracted from pure data, however, how it is classified into twenty nine hierarchical land use types is defined by the FICM manual [16]. Also, the colors used to visually represent land-use types in our model are the colors proposed on the CMPU manual [17]. Mapping the information from the tree database, such as tree location or tree canopy, to vector-point information is a literal visual representation from data to icons, but the tree typology we use is defined by the CMPU manual.

6.2 Conceptual Knowledge

Conceptual Knowledge refers to “the interrelationships among the basic elements within a larger structure that enable them to function together” [25]. This refers to the structure of the model and the organization of its components. For example, the set of layers to organize the data came from the FCIM, which provides the categories for all space types for university campuses; information that is not only categorical, but also related to
budget estimates for specific design proposals. From the case study, a main structure for the campus intermediate scale model emerged to classify the project into: Projects, collection of Projects –or Scenarios– and alternative projects for Scenario Comparison; All of them scheduled in a timeline that help the planners and designers to define which project or scenario alternative responds better to a set of constraints and material and immaterial goals, such as budget and satisfaction respectively.

A set of design guidelines and expert best practices are compiled in the CMPU document, which has the goal of achieving a “livable, sustainable and beautiful campus.” [17]. For our campus, there are three main sets of guidelines. One refers to earthwork and water and includes landform and grading, storm water management, watercourses, etc. Another is vegetation, which contains guidelines for tree protection, tree replacement, plant selection, irrigation, etc. The last are guidelines for hardscape, which provides rules for circulation, pavements, facilities, stops, furniture and lighting among others.

6.3 Procedural Knowledge

Procedural Knowledge refers to “the methods of inquiry and criteria for using skills, algorithms, techniques and methods” [25]. In the context of this project, we classified into procedural knowledge the processes that are implied on the decision-making process for a master plan. From experts’ perspective, evaluations of the projects are processed under several criteria such as economic, capacity (number of parking spots), areas (green areas by zone, total green areas), among other criterion that impact landscape decision-making. We designed our model so the evaluation outputs are visualized on the dashboard display, as informative bar graphs and pie charts that update in real-time, to give feedback to users for each decision.

Additionally, by incorporating experts’ understanding of problems from city planning workshops, we defined and incorporated some software commands, such as new measurement for distances –minutes’ walk, or the concept of parametric street sections explained in the previous section, which maintain the through-width, modifying the median and sidewalk, but maintaining entities. Other commands, such as tree replacement, are conditioned to the tree status, evaluated under a set of case parameters.

6.4 Meta-cognitive Knowledge

From a cognitive perspective, Meta-Cognitive Knowledge is the “…awareness and knowledge of one’s own cognition” [25]. From the perspective of a landscape planning tool implementation, it is the metastructure of the model itself. What are the design strategies, the context, and the conditions of such models? For the CLIM implementation process, the Meta-Cognitive Knowledge catalyzed the hardware and software user interface design and the Unified Modeling Language (UML) software structure.
The hardware and software user interface is designed to support collaborative landscape design and planning with several stakeholders. The organizational layout regarding scale and orientation of the physical features of CLIM responds to the collaboration and interaction among experts (as observed in the board meetings regarding the case study). Physical features such as a horizontal 55-inch multi-touch screen allowing direct interaction with the real-time visualization of campus top view. The edge of the horizontal screen nearest to users displays icons that control design and planning commands, such as ‘create’, ‘select’, ‘delete’, and ‘modify’ land types, lighting, parking spots, trashcans, recycling cans, and trees and street trees. CLIM tool also has a vertical component, a 55 inch screen component, which presents a dashboard that displays real-time updates on graphs (i.e. percentages of land types, water savings, tree types, etc.); number of elements (i.e. number of trees, number of parking spots, etc); project information (comparison between two alternative projects); and real time assessments of aspects of the model (green areas goals, water efficiency, cost) to more easily comprehend constraints, assessments, and goal achievements [14,15].

Unified Modeling Language Structure (UML) is a language we used to model the application structure, its behavior and architecture, as well as its process and data structure. The UML model helped us to more clearly identify the elements and structure of categories that are used in a landscape-planning project. Fundamentally, CLIM has two major project classes: Building Project.
and Non-Building Project. A Landscape Project is a sub-class of the Non-Building Project class. There are four types of Projects: New Project’, ‘Demolition’, ‘Addition’, and ‘Renovation’. These actions are the project types, and one—or all of them—composes a project. Additionally, to organize the information in a way that is understood by experts, projects are classified by space type. Landscape projects are classified using four (of the nine) space types suggested by CMPU: Green Areas, Athletics, Parking, and Green Roof. Through this classification we create the project instance and scenario structure, and they are attributed with a set of space types. Additionally, each space type has surface materials and element types associated with it, such as grass, meadow, green roof, water pond, concrete, asphalt, trash cans, lighting, signage, among others. The above list was previously described in the Factual Knowledge section.

7. PARADIGM SHIFT: FROM TRANSFERING TO MODELING

The design, organization, and implementation of such amount of information and knowledge in all of its categories are incredibly complex. The UML design structure itself is composed by hundreds of classes and objects that represent not only physical components and attributes but also their relationships, all of them founded on collections of elements such as land use types and trees inventory. At the level of Algorithms and procedures, the set of variables, parameters, and constraints a designer uses toward decision-making varies depending on the goal. Analysis, evaluations, and assessments that guide planners’ decisions towards specific goals are embedded into the tool as a set of algorithms and procedures that can be accessed from a menu when needed. At the level of Models and Structures, the structure of the information and how to access and store it, requires a set of organizational structures such as Layers for co-spatial information, Zones for grouping spatial elements and attributes, Projects for grouping actions, and objects’ attributes such as owners, budget and schedules; and Scenarios for grouping projects in a wider perspective.

The types of questions that CLIM is designed to answer, respond to the Where, How, Which, When, Is/are and Why question types. These questions types combined with static variables —such as area selected, area type, a specific condition, a budget, a capacity, an element—, and temporal variables —such as dates, capacity, flux of budget— towards goals —such as costs, performance, percentages and number of elements (figure3)— create the more literal and comprehensive questions to be answered (figure 4): “Where on campus can we find this type of area?”; “How many parking spots are in this selected area?”; “What percentage of green space is in this project zone?”. Other more comprehensive questions are the ones that imply an evaluation or comparison for an answer: “Why is this scenario more suitable than the second one?; If the green space increase in this zone, how does it affect the general
Beside all the information—and the one structured by expert knowledge—needed to answer those types of questions, the question that arises is not what is the information we need to access to build a ‘complete’ model, but ‘Why do we need to access it?’ or ‘What is the underlying reason we need all of this information, stored in such a way, accessed at such a time.’ The main reason is not only to assist design as several Computational Aided Design (CAD) tools do, but also to offer a platform that support design decisions toward spatial design goals. This reason implies a number of operations that are qualitative rather than quantitative. However, they are based on quantitative information, which should be accessed through a structured model. At this moment we realized that it does not matter how big are the stored databases, and how accurate the command menus are for each design scenario. What matters is whether the tool is able to offer us qualitative assessments. With that goal in mind we extended our research toward the qualitative aspects of landscape design, led by the main goals presented in the fundamental manuals we used to extract experts’ knowledge. Qualitative goals such as “Create campus legibility/orientation” and “Unify the campus and create a sense of place,” among others. For these types of goals, we focused on the usability of the campus and developed a causal model that help us structure the way of measuring qualitative aspects through effectiveness, efficiency and satisfaction of campus users. We developed a structured model or causal model—a graphical causal diagram that shows potential causal relationships between variables in a model—that help us describe the mechanisms of a system that allows a level of legibility/orientation and sense of place, for example.
8. SATISFACTION CAUSAL MODEL FOR LANDSCAPE DESIGN

The causal model helped us recognize the most influential qualitative aspects of the campus landscape. The model collects all causes that may have an impact on the landscape performance. To construct the causal model we gathered all aspects and elements that are part of the campus landscape that may have an effect on user satisfaction, from buildings and their attributes to interstitial space and its characteristics. Also, more intangible aspects such as management and maintenance, including the number of employees and distribution of resources; to much more abstract aspects, such as the perception of space and place.

Users satisfaction has several causes. We classified them into four main threads: Management, Sustainability, Identity, and Space and Space Use (figure 5). Management includes maintenance and operation of spaces, construction and implementation of projects, which in turn have implicit variables such as hiring workers for specific jobs and goals (i.e. excellence in academia, excellence in sports, perception of success). Sustainability, understood as performance landscape, includes aspects such as water collection and management, trash and recycling networks, cleanliness and perception of cleanliness, comfort, and perception of sustainability, among others. Identity is the most qualitative thread, and it includes aspects such as familiarity, sense of community, sense of belonging, and sense of identity, among others.
Space and Space Use thread has more quantifiable aspects since it includes spatial connectivity, visual connectivity, accessibility, ease of wayfinding, among others. Management and Space Use influence Sustainability and Identity.

After we constructed a full model, we held a series of unstructured interviews with landscape designers with at least ten years of experience. We asked them to review the model, and we recorded each interview, while they modified the model adding or removing concepts based on their understanding of the model. We repeated the interview five times, updating the model after each interview, so that the model evolved until there were minimal changes needed. Some elements that were deleted from the model were: architecture style, aesthetic, and sense of living and learning environment. Added aspects were: salaries, excellence in academia, zones of natural species, and ecology-human interaction along with new cause-effect connections. All the modified elements are represented in color in figure 5.

When comparing the model against the existing literature on landscape design, “sense of identity” is one of the most crucial qualitative goals. Therefore, we focused on satisfaction through the lens of sense of identity. With this goal in mind, we conducted a series of interviews with landscape design experts that guided us toward restructuring the initial causal model, recognizing that the sense of identity is regulated by five main qualitative
aspects: Sense of Place, Sense of Community, Sense of Space, Sense of Belonging, and Sense of Control. Each of these sub-factors, thus, is influenced by a set of quantitative and qualitative measures that can be computed directly from explicit data or social behaviors, such as the amount of lighting and visibility or familiarity and level of attachment.

9. DISCUSSION

We hope that these latest approaches, which, to the best of our knowledge, have not been used to measure the qualitative aspects of landscape for the purpose of being included in a computational knowledge-based model, are a significant contribution for the Design Computing field to continue its development toward the support of complex evaluations along the design decision-making processes.

The implementation of qualitative goals into the knowledge model is a work in progress. Its next steps are: First, to complete the measurement of specific causes of users’ satisfaction as the ones we described above. Some of these aspects are quantitatively measured at the level of evaluation knowledge. Some of them are: space and space use, spatial connectivity, and visual connectivity. Second, to measure other qualitative aspects that cannot be directly measured from evaluations based on raw information or knowledge models, but collected through social studies such as surveys, and translated into information to support decision-making. Currently, we have a list of a series of tests we need to run in order to capture the qualitative aspects mentioned above, specifically the aspect that would have more impact on the performance of the landscape design of a campus: sense of identity [26]. As this aspect and all the ones that relate to it –sense of place, sense of community, sense of space, sense of belonging, and sense of control– are qualitative and abstract enough to be measured by quantitative approaches [27,28], we have designed cognitive map surveys, a mapping survey, a campus picture familiarity survey, and a daily-route map survey to recognize “path profiles.” Also, a focus group will be held to help us clarify those findings. These studies are currently under review, and they will be focused around our university campus.

We expect to corroborate that “campus identity” is the most important measurement relative to campus landscape performance. The expected results are a set of campus maps, which will represent different qualities. Sense of safety, sense of control, the perspective of iconic buildings, and key photo-spots will be some of the aspects that will compose the “sense of identity aerial map”, “sense of safety map”, “green perception map”, among others. The final and long-term goal is to obtain qualitative feedback about campus design alternatives and correlate them to quantitative measures of the environment.
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