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Developing knowledge based design education method: using generative systems and ontology to teach landscape design

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Abstract

The objective of this paper is to propose a database for landscape design solutions to help students learn basic design concepts and assist them in applying this new knowledge by using solutions developed by experienced architects as references. The system is based on an ontology that contains design concepts and instances. The necessary information for understanding a concept is represented by means of schematic rules from a shape grammar, and each concept is connected to one or more design instances (solutions). The first step for developing this system consisted of setting up the taxonomy for the ontology. This taxonomy was based on the structure of Christopher Alexander's pattern language and the hierarchical structure of different landscape books and manuals. A prototype of the system was developed, with examples of good design practices taken from the work of Brazilian landscape architect Roberto Burle Marx. In addition to the structure for researching design concepts and precedents, an interactive module was also created, implemented in a parametric design tool. This module enables students to generate solutions in a digital model and automatically insert different parametric components, such as groups of trees, bushes and sculptures, etc. The effectiveness of the system was verified in a workshop held with undergraduate students. The tests helped confirm that the use of the system can assist in the teaching process, without infringing upon the quality of the students' design solutions. In the near future, the plan is to implement an online version where students will be able to insert new concepts and precedents, thus expanding the system.

Keywords: Ontology. Roberto Burle Marx. Landscape architecture. Pattern language.

Introduction

According to Sweller (1994, pp. 295-296), when an intellectual ability is newly acquired, it can only be utilized with substantial cognitive effort. With time and practice, its application becomes automatic and requires less mental effort to operate it. Until this happens, performing tasks is slow and prone to error. Despite the difficulties that arise from studying a new subject, this does not mean there is always an appropriate learning method that will contribute to greater teaching efficiency.

For example, according to Akin (2002, pp. 407-409), the teaching method in design courses can cause motivational problems and shortcomings in the learning process. The author argues that instruction based on tests, applied under pressure, with criticism aimed at the students' work can be unproductive, apart from demoralizing and destructive. This method contributes toward making the first design experiences of students, who are in the process of learning a new skill, an extremely difficult task.

Over time, these experiences, according to Gero (1990, p. 27), are transformed into generalized concepts or groups of concepts at different levels of abstraction that are schematized by the designer. These schemes are comprised of concepts from a set of cases and form a class from which new solutions can be inferred. The idea of schemes dates back to the studies of Bartlett (1958, p. 168) on human thought and memory, in which he developed the notion of internalized image. According to the author, a scheme represents an active organization of past experiences, which can be used to structure and interpret future events. Experienced architects, unlike students, already have a number of schemes, formulated from past practices, which are able to help generate countless solutions. Due to their inexperience, students have great difficulty in establishing organized schemes, since they do not possess the knowledge of a qualified professional.

As a result, students often tend, for example, to omit a particular concept for solving a problem or do not give due importance to a principle that was taught in the classroom. They can also handle information improperly and, in their solution of a problem, generate many other unnecessary ones. In other words, they have a difficult time associating generalized concepts from their early experiences and understanding the rules and properties for using them. The professor's mission is to teach them how to correctly organize a design problem and help them with the task of selecting the concepts needed to come up with an appropriate solution. This is not a simple task and one of the methods most used to overcome the difficulties students face is the utilization design references.

References are solutions developed by experts – experienced architects – used to exemplify what would be a good design practice. Although this form of teaching often functions satisfactorily, students end up learning on the basis of a final result, without having access to the information used during the development process of the solution. Consequently, they experience difficulties in applying principles appropriately and need an advisor to help them process information. Professors scarcely have the time to answer all the questions that arise in the classroom and this leads to basic design errors, which usually come to light at later stages of the work.

The intent of this article is to present the findings of a study that proposes a computer-implemented system to provide students with support during the decision-making process for solving design problems. The model that was developed hooks up design concepts, schemes and precedents through an ontology (GENESERETH & NILSSON, 1987). As will be seen below, the concepts in the ontology are represented by vocabulary found in the universe of discourse of designers. The schemes are defined by the application of this vocabulary, by rules from a shape grammar (STINY, 1972), and the precedents illustrate instances of these schemes. The hypothesis of this study is that using a system based on design concepts, schemes and precedents can contribute toward increased teaching efficiency without hindering the quality of the work or the creativity of students.

The article addresses two important stages in the research process. The first entails developing a model that adequately hooks up design concepts, schemes and references, and the second deals with validating the hypothesis of the research. In the sections that involve the development of the model, different subjects will be broached, such as the language patterns of Christopher Alexander (ALEXANDER, 1977), cognitive load (SWELLER, 1994) and shape grammar (STINY, 1972). The sections related to validating the hypothesis deal with the methods and materials used during one of the exercises in which students developed landscape design solutions with the help of the system, through the creation of a digital model in a visual parametric modeling system. Thus, all the stages of the process for formulating the solution occurred in a computer environment.

In the prototype developed in this research, the system is filled with concepts found in the universe of discourse of a landscape architect. In this case, the schemes and precedents were taken from the work of landscape architect Roberto Burle Marx. This designer was chosen because he is deemed an expert in the realm of open space design. According to Macedo (2003), although Burle Marx is not the only big name in Brazilian landscape architecture, his importance is undeniable, not only nationally, but worldwide. The author argues that the quality of his designs is renowned, and his creations can be considered global benchmarks in landscape architecture. Consequently, his work contains a significant portion of the concepts and schemes pertaining to the universe of discourse in landscape architecture applied in solutions that can be considered important design references.

Model of the system – how to organize knowledge?

In 1637, Descartes published the famous treatise entitled Discourse on Method. In this text, the author put forth a method of reasoning for solving problems in order to arrive at scientific truth, which was divided into four precepts:

> ***The first was never to accept anything for true which I did not clearly know to be such; that is to say, carefully to avoid precipitancy and prejudice, and to comprise nothing more in my judgment than what was presented to my mind so clearly and distinctly as to exclude all ground of doubt. The second, to divide each of the difficulties under examination into as many parts as possible, and as might be necessary for its adequate solution. The third, to conduct my thoughts in such order that, by commencing with objects the simplest and easiest to know, I might ascend by little and little, and, as it were, step by step, to the knowledge of the more complex; assigning in thought a certain order even to those objects which in their own nature do not stand in a relation of antecedence and sequence. And the last, in every case to make enumerations so complete and reviews so general that I might be assured that nothing was omitted.***

Descartes' suggestion for solving a complex problem is to divide it into simpler sub-problems as many times as necessary, then solve these and, afterwards, assemble the results to arrive at a conclusion on the main problem. On the basis of this approach, a strategy was formulated for developing algorithms in the field of computer science, called "divide and conquer". In an algorithm of this type, complex problems are broken down until the resolution process is simple enough to obtain a response. The solutions are then combined in order to obtain a general solution (CORMEN, 2002). This same type of structure can be detected in Christopher Alexander's pattern language.

Pattern language is formed by a series of information units called patterns. Each pattern contains the body of knowledge needed to solve a specific design problem, that is, a small scheme for solving problems described verbally, associated with illustrative diagrams and images. The patterns always have the same format, i.e., the information is structured in the same way in all of them. In the book ***A Pattern Language***, 253 patterns are arranged in ascending numerical order. Those with lower numbers deal with large-scale design problems, such as the town. Higher pattern numbers correspond to minor issues involving, for example, the scale of a building or garden. Each is connected to other patterns forming a complex network. At first sight, what's important in Alexander's language is this structure of direct connections between patterns, as shown in Figure 1.

However, the patterns are also organized according to a hierarchy of classes which helps readers quickly locate the unit they wish to use. The Access to Water1 pattern (number 25), for example, belongs to the Character of a local environment2 superclass. This, in turn, is a subclass of Town3, which belongs to the Pattern language superclass. See scheme A, which is presented in Figure 2.

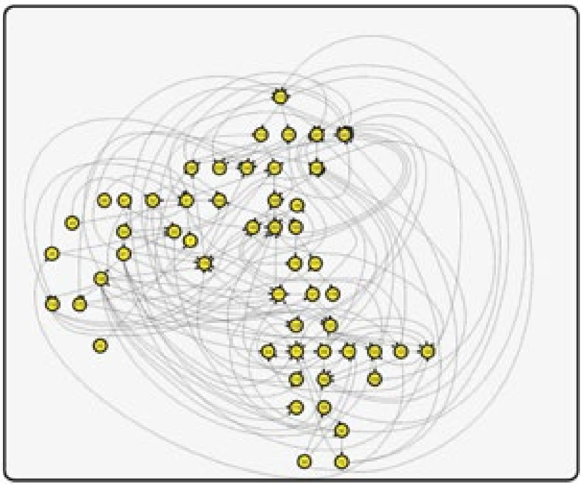


Figure 1

Graph showing the network of relationships between the different patterns in Alexander's language

Source: authors

This organizational structure Alexander developed is suitable for modeling, as will be seen in the part of the system that relates to the organization of design concepts and schemes. However, in Alexander's pattern language not much importance is given to the instances that the patterns can generate, in other words, the solutions or precedents. In his system, the references, illustrated through images, represent a single pattern. However, an image of a building or open space can represent more than one, since the architect, when creating the design, gathers a number of patterns (or schemes) and applies them simultaneously to develop a solution. In order to externally associate the design references with the patterns, it was necessary to seek alternatives that would enable the taxonomy of the system to be complemented. One of the methods used to obtain the final model was achieved through the study of organizational structures of different landscape architecture manuals.

Manuals are a type of pattern book whose purpose is to list all the information about a subject. It is not necessary to read them in a linear fashion, but they can be read in a way that is precise and targeted to what is being sought, since the knowledge is separated into blocks of information. Each of these units provides the data necessary to solve one or several design problems. In some cases, the manuals contain examples of solutions developed by a designer in order to illustrate the concepts and schemes being presented. The way knowledge is

1. Access to Water

2. Character of a local environment

3. Towns

organized depends on each author, and some authors create structures divided more into sub-sections, with more standardized content. In some ways, they resemble Alexander's pattern language, but they do not have the same degree of formalization in their structure or content.

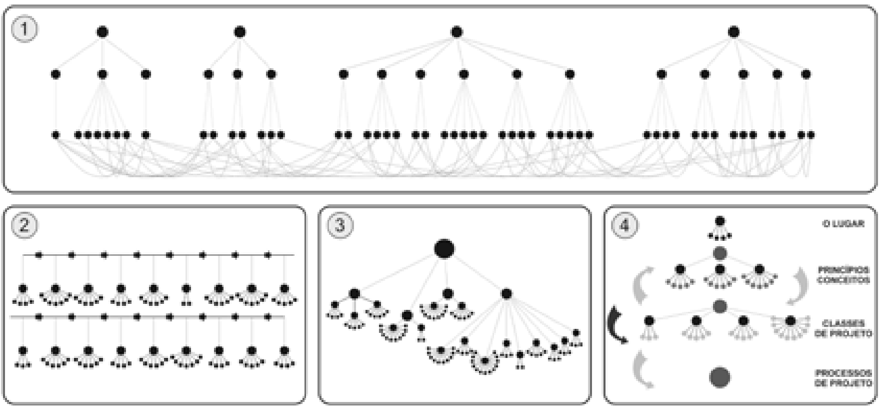
At this stage of the study, three more books were selected, apart from the manual with Alexander's patterns. From these, diagrams were prepared that show how their information was structured. Figure 2 illustrates different forms of organization developed by their authors.

Scheme 1, in Figure 2, was constructed from the book ***A Pattern Language***, by Alexander (1977). In it, one can see the organization of the patterns as explained in the previous section. The second structure presented was elaborated from the index of the book ***Landscape Architecture*** by Simonds (1997). This landscape architecture manual has good design practice "rules", although the information is not standardized for solving a problem. The breakdown of the chapters according to themes, such as circulation, building of spaces or water in the garden, represents a subdivision and classification of design concepts. However, there is no clear organization for presenting the references to the reader.

FIGURE 2

Schemes developed from landscape books (scheme 4: place. main concepts, design classes, design processes)

Source: prepared independently



The Landscape of Man (JELLICOE, 1975), the third book studied, presents a historical approach to landscape architecture. In this case, it is not a manual with different design concepts, but a collection of gardens (instances) that seeks to exemplify different periods of man's domination over landscape. The book can be read in a linear manner or by zeroing in on different sections, since most of the characteristics described in each section can be understood without having to read what came before. In this book, the information about design concepts, used in different historical periods, is taken from an analysis of the instances. These principles help to classify each of the gardens as belonging to a period.

The fourth and final structure was elaborated according to the organization of the content found in *The Poetics of Gardens* (MOORE, MITCHELL & **TURNBULL, 1990**). This book ascribes the same importance to instances (actual examples) and design concepts and schemes. The first chapter indicates the need to understand the *Genius Locci* in order to start the process of assigning the variables of a design problem. In this stage of analysis, the designer organizes the information that will provide the necessary foundation for developing an idea.

The second chapter contains the main concepts and components that a garden must have, that is, the knowledge that should be applied to the variables assigned in the previous stage. This content is divided into sections for the purpose of classifying the different design concepts. The information is presented in text format, together with images, illustrations and diagrams that make it easier to understand.

In the third chapter, the four classes are defined – collection, pilgrimage, scenarios and symmetries. Each contains a series of gardens that represent good design solutions. They are clearly and objectively described, and a clear relationship exists with the principles taught in the preceding chapter. Thus, there is an organized way to associate instances and concepts.

The last chapter of the book presents five different dialogues between the designers responsible for creating the gardens described in the previous chapter. In each dialogue, there is a discussion that illustrates the process of searching for solutions to design problems that landscape architects would presently encounter. This shows how design concepts, even from former gardens, can be used to solve present day problems.

Using the structures described above, a model of the system was formulated. It contains features of the organization found in Alexander's patterns and in the work *The Poetics of Gardens*. On the left side of the diagram (Figure 3), in the DC (design concepts) superclass, the concepts are organized into three different subclasses (GREEN, BUILT and WATER). The schemes are formed by combining one or more concepts, and these are connected to each other, thus forming a network of connections similar to the language of Alexander's patterns. On the right side of the diagram, in DE (Designs), there are two subclasses which are PD (past designs) and FD (future designs). Each one of these has four subclasses, which are SC (Scenarios), PI (Pilgrimage), CO (Collection) and SI (Symmetries). Stored in them are past and future designs. These classes also have connections that link them up with organized design schemes on the other side of the diagram. With this system, students can use these concepts and compare their solutions – designs from the present – with those developed by the Brazilian designer. In the model of the system, it can be noted that relationships between one precedent and more than one scheme can occur, since in a design image it is possible to identify schemes with different degrees of complexity.

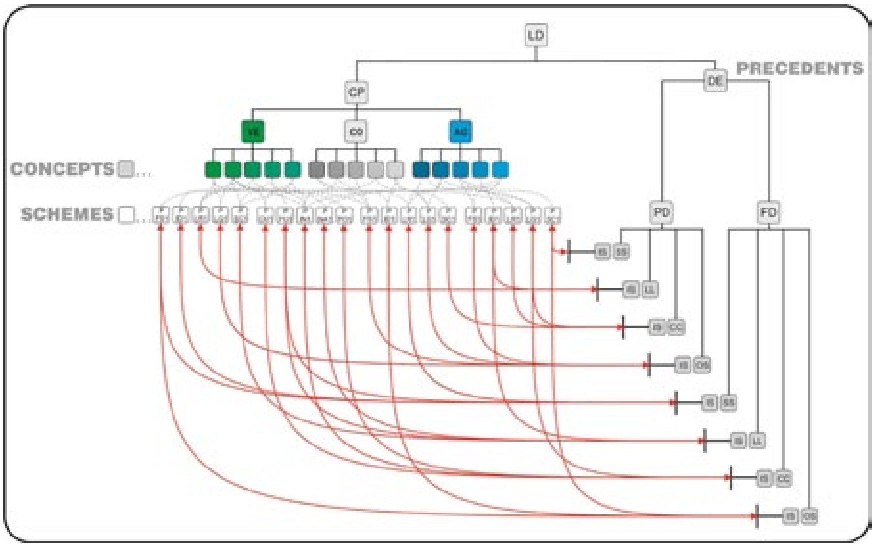


FIGURA 3

Class hierarchy model of the system

Source: authors

Representation of information – vocabulary as concepts, concepts and rules that form schemes

In 1956, George Miller conducted studies which demonstrated that the human cognitive system can only process 7 ± 2 digits simultaneously. If this number of elements is exceeded, reasoning and learning are impaired. On the basis of Miller's work (1956), research has been conducted, for more than 25 years, resulting in the principles that today form the basis of the cognitive load theory. Some cognitive activities, according to Clark, Nguyen & Sweller (2006), have a lower load, such as 'learning the vocabulary of a language'. On the other hand, 'creating sentences with those words' entails a greater cognitive load. An appropriate learning environment, according to the principles of Cognitive Load Theory, minimizes unnecessary mental resources and thereby maximizes learning.

As seen above, the patterns in Alexander's language (1977) have the same format. However, even with all the patterns containing the same elements, using them is complicated because each one contains a large amount of information, thus representing complex design schemes. Furthermore, when designers attempt to work with Alexander's language, they are working with not only one, but countless patterns. Thus, using such a highly complex system in the classroom becomes unfeasible. The way to circumvent this problem entailed working with less complex schemes, represented by rules and derivations of a shape grammar. The use of shape grammar schematic rules (STINY, 1972) allows for faster reading and understanding of the information needed, without overloading the student. Through these simpler schemes, students can solve a complex problem and then gradually add more content, thus forming new, more sophisticated schemes.

Since the goal of this work was to implement a prototype that would assist in developing landscape designs, only the concepts related to this field of knowledge were incorporated. These were "translated" into a grammar shape vocabulary and grouped into three classes that are part of the model seen in Figure 4. The first one, as explained above, is called **GREEN** and includes terms as such as tree, palm tree, bush, etc. The second is called **BUILT**, comprised of colonnades, pergola, roofing, etc. The third class is called **WATER**, which encompasses concepts such as lake, waterfall, fountain, reflecting pool, etc. The distribution of these concepts according to these classes enables them to be properly organized and found in the system. However, if these concepts are accessed without a rule stating how they can be used, they do not serve much purpose. They are like words of a vocabulary which, when standing alone, only have their intrinsic meaning, in the absence of a specific context. Therefore, rules are needed that will allow for the proper use of concepts. Basically, three were considered for the prototype: at a point, along a line and in an area. These forms of insertion, as noted by Moore, Mitchell and Turnbull (1990), can be identified, for example, in the English landscapes of Capability Brown. According to the authors, the landscapes created by this English designer were formed out of very few elements – rolling fields, isolated trees (**POINT**), groups of trees (**IN AN AREA**) and rows of trees (**ALONG A LINE**), in addition to water, cows and the English sky.

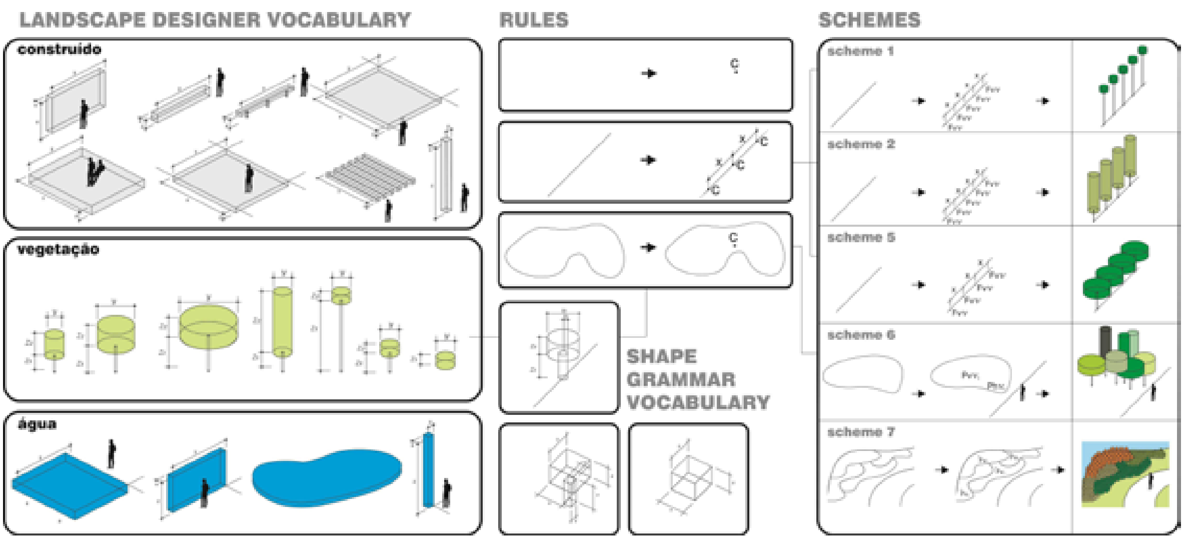


FIGURE 4

Class hierarchy model of the system

Based on these three forms of insertion, rules were formulated in order to place the concepts in schemes. Listed below are some examples:

- A lone tree or palm in a bed;
- The linear insertion of components, which could be represented by a series of palm trees along a path;
- The insertion of components in an area, which could be formed, for example, by a forest with one or more species of trees.

These are simple schemes which can be found in the work of most landscape architects. Besides these, the system also contains schemes that are repeatedly found in the work of Burle Marx. Examples of these situations, as was explained, can also be identified in the other branch of the model, in which design precedents (instances of schemes) are organized. Each scheme has a number of properties which enables the user to utilize it correctly. For example, the scheme 'palm trees along a line' has the properties needed to create a translucent vertical plane and it can mark a path or direction. If a landscape designer were to use it to create shadows along a path, he would be making a mistake. In this case, it would be more appropriate to use the scheme that inserts trees with horizontal canopies along a line.

A prototype of the system was deployed in an application able to create graphs with interactive nodes called TouchGraph Navigator. This program has different visualization features that enable it to represent the hierarchical structure of concepts, schemes and precedents. The database of the application can be obtained from files with different formats, including Excel. From these, a dynamic graph can be modeled which shows the relationship between the nodes that are generated. In addition to these relationships, it is also possible to assign attributes to each one of them, in order to provide additional information when selected by the user.

Testing the system

The system was tested through a workshop in which a landscape design exercise was conducted with students from the fourth year of the Architecture and Urbanism course in the School of Civil Engineering, Architecture and Urbanism at UNICAMP. The testing was carried out during the first classes of the course AU118 (Theory and Design VIII: Complexity). This class was selected for the experiment because fourth year students have already completed the landscape architecture courses.

The work was based on a landscape architecture design exercise that is given to classes from the first year of the Architecture and Urbanism course of the School of Architecture and Urbanism at the University of São Paulo. The goal of this exercise is to teach students architectural composition concepts by the modeling of terrain and composition, using elements that represent the components of an open space. The material used to perform the task is a box of wood that is one meter long, fifty centimeters wide and approximately fifteen centimeters high, filled with sand. Within this volume, students can model a fictional space as though it were a terrain. In order to compose the area, students look for small sticks, pieces of wood, Styrofoam, paper – basically, any kind of material that would help perform the exercise. The experiment that was proposed to evaluate the system has a goal similar to that of the sandbox exercise. However, in this case, students did not develop physical models in order to obtain a solution to the problem that was posed. The tools used for the tests involved the utilization of digital models.

The same rules used for representing the patterns were deployed in a parametric modeling plug-in of Rhino, called Grasshopper. A definition4 was formulated for each one that would make it possible to reproduce the same schemes identified in the work of Burle Marx, as well as many others. Figure 5 shows the basic structure of the diagrams generated for all the definitions in this stage of the research. Essentially, these are divided into four different parts: in the first one, the user can define the dimensions and type of component by manipulating numerical control bars, buttons or entering codes. Following this, there is a module responsible for calculating and setting the exact position of the components. This block of objects from Grasshopper can perform tasks pertaining to the rules for insertion at a point, along a line or in an area. After this module, the geometries are inserted, which would correspond to the grammar vocabulary. The last module, common to all the definitions, is responsible for determining the type of component that will be inserted. The user decides which component (Green, Built and Water) will be in the first part of the algorithm (parameters), since this block establishes a color for the geometry that is inserted.

FIGURE 5

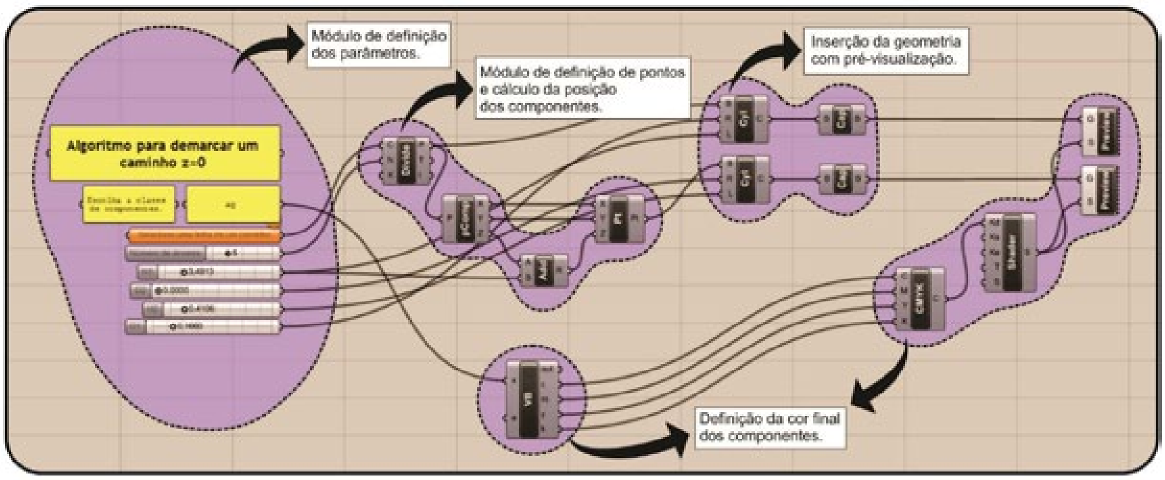
Example of one of the definitions formulated in the research

(The translation of texts in the figure from left to right: Algorithm for demarcating a path z=0;

Choose the class of components; Select a line of a path; Number of trees; Module for defining parameters;

Module for defining points and calculating the position of the components; Insertion in the geometry with pre-visualization; Definition of the final color of the components)

Source: authors



4. Name given to the file from Grasshopper

In total, five different definitions [Figure 6] were formulated, one for insertion at points, two for insertion along a line and another two for insertion of components in an area. In the case of insertion along a line, a variation was created which does not distribute the components individually, but as a barrier, for example, a built or green wall (in a continuous manner). With respect to insertion into areas, two definitions were also programmed. The purpose of one of them is to introduce components, in the digital model, that are equally spaced and have the same dimensions. The other one inserts components of different sizes that are heterogeneously distributed. These last two algorithms are primarily used for forming areas with shrubs or trees.

FIGURE 6

Instances generated with the five definitions formulated in grasshopper.

The translation of texts in the figure from top to bottom: Component at a point (similar model to the green sculpture of Banco Safra); Components along a line; Single linear component; Components in an area (heterogeneous distribution); Components in an area (homogeneous distribution)

Source: authors

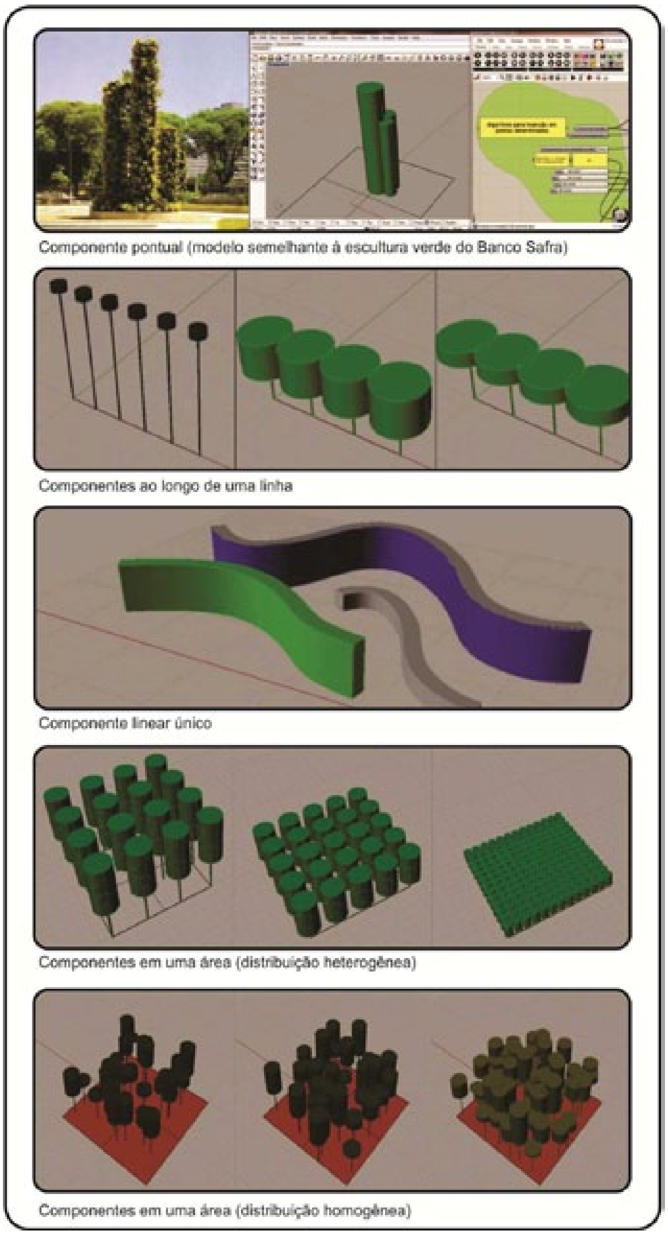
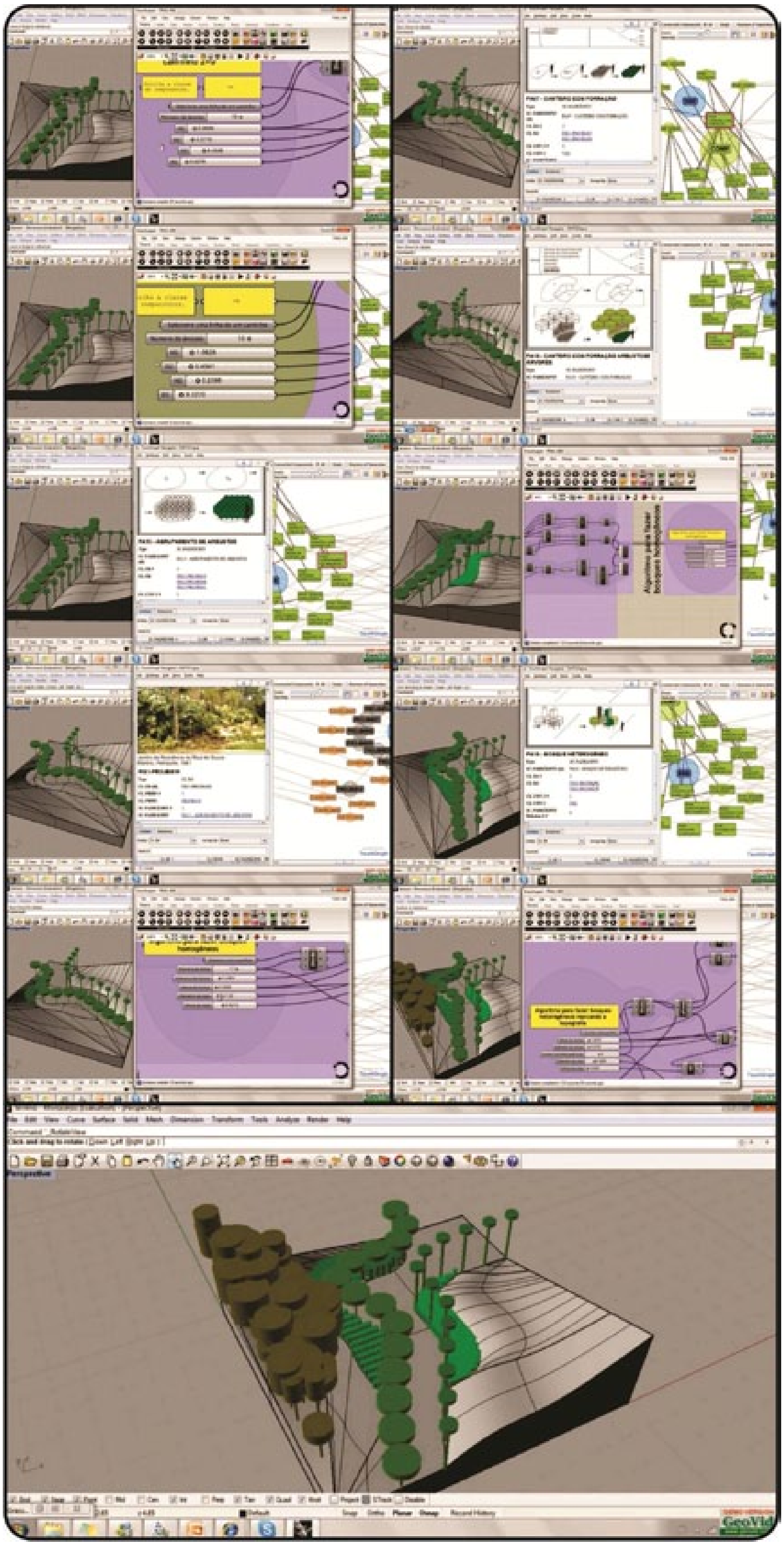


FIGURE 7

Sequence for formulating the solution and the final result.

Source: authors



Based on using the definitions from Grasshopper, it is possible to build parametric models representing different solutions for the same design problem and, at the same time, research design concepts, schemes and references in the prototype of the system. Figure 7 shows the process for developing a model using these tools. The smaller images illustrate the sequence for inserting components according to the different rules and the final result.

Workshop results

The workshop for testing the system was carried out with the assistance of 18 students, who were divided into groups of three. The reason this configuration was chosen for conducting the experiment was due to a concern about possible difficulties that students might encounter while using Grasshopper for parametrically modeling their design solutions. If that were to happen, it would not be feasible to individually assist all the students while they develop their virtual models. In groups, students can help each other, thereby enhancing the efficiency of the process. Before starting the exercise, a class was given to explain how they should research concepts, schemes and precedents in the system and how they should use Grasshopper to develop a solution.

The environment in which the students would perform the work had already been built with the help of the Rhino modeling application, featuring a circulation design plan view. After researching the references in the system and drawing a sketch, the groups began to work with Grasshopper, inserting components in Rhino through using the definitions. Figure 8 shows students conducting research in TouchGraph Navigator, as well as the process for using the Grasshopper definitions and an example of a solution.

FIGURE 8

Students develop solutions in a parametric modeling environment, assisted by the prototype for researching concepts, schemes and references.

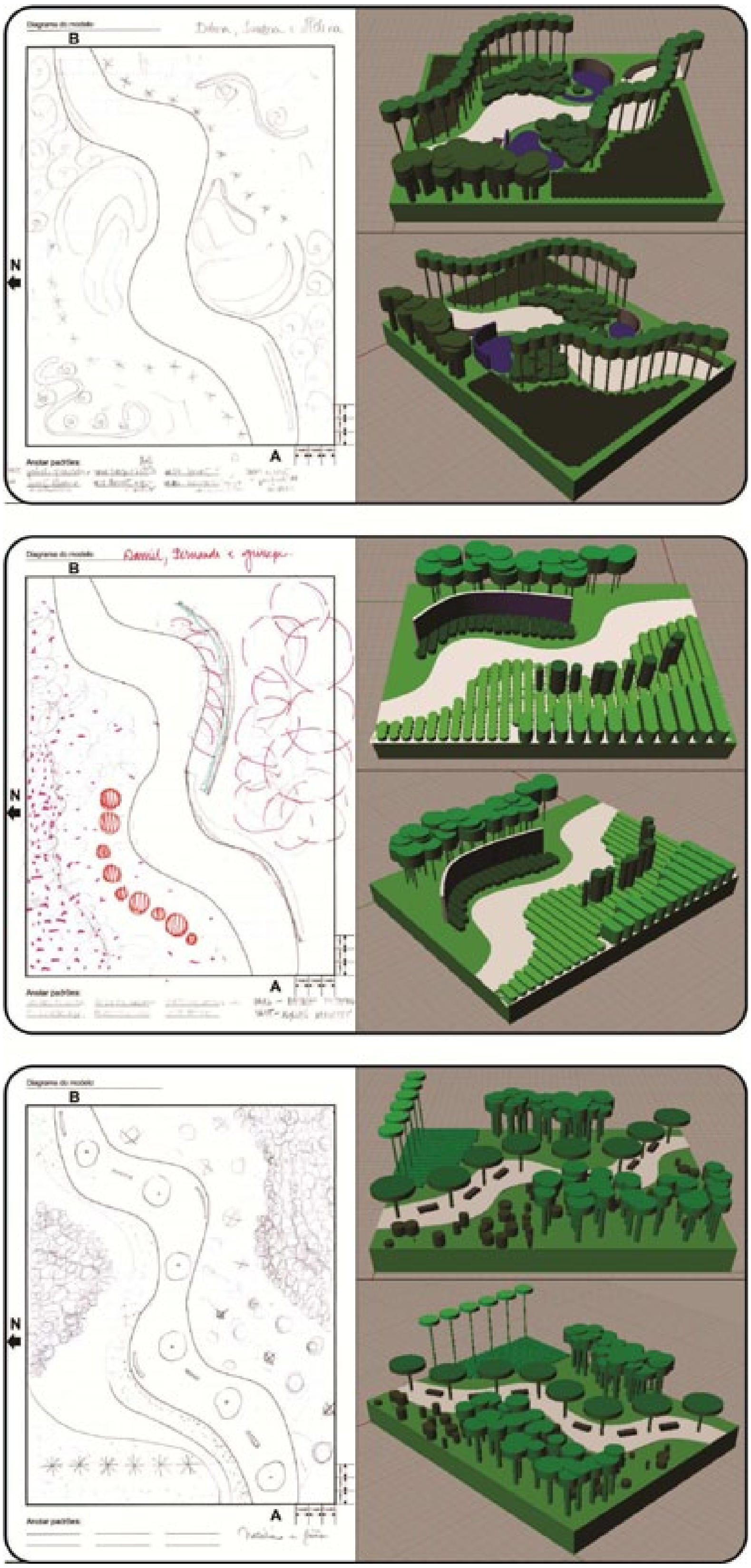
Source: authors

Figure 9 contains some of the models developed during the workshop. Next to each one is the image of the sketch drawn by the students. In comparing the two, it is important to note that the digital geometric models and sketches are similar. This indicates that the students were able to almost entirely translate their ideas from paper to the computer through using Grasshopper. If they were to have had problems using the definitions for inserting the components parametrically into Rhino, the digital models would probably have been different, since the students would have sought alternative routes or simplified their ideas. It can also be noted that the use of the definitions and the prototype with the concepts, schemes and references contributed toward the students seeking to develop solutions in order to compose the space and not simply view them as elements for filling purposes. It's important to mention that, during the process, students did not receive any kind of presentation on composition principles in landscape architecture. Thus, if this were a real teaching situation, the professor would have more time to work with other landscape architecture concepts, because the system would be providing students with support in more basic design issues.

FIGURE 9

Examples of solutions designed by the students.

Source: prepared independently



Conclusions

As seen, in the system that was presented, shape grammar rules were used, which proved to be adequate for representing design concepts and schemes. Through them, it was possible to systematize and render more objective the information that was introduced. The use of derivations representing schemes, in conjunction with the references selected from the work of Burle Marx, did not cause the students to start designing like this landscape architect, according to his style, but it did help them be able to arrange, in a more organized fashion, the elements that make up a garden. The system truly served to be a tool that assisted and collaborated during the design process.

In this study, as was explained, designs of Roberto Burle Marx were selected as references, due to him being one of the great Brazilian open space landscape designers. Using these references, schemes for organizing the compositional elements in his gardens were identified. As a result, the prototype can be considered an important tool to understand how this landscape architect composed his open spaces. References from other architects, besides landscape designers, could also have served as a basis for developing the system. With this system, it would also be possible to study the designs of other architects whose work is systematically used as a precedent not only for students, but also by other architects.

Furthermore, the system for researching design references and schemes has the potential to be used as a knowledge base in which data can constantly be added by users. During the information analysis phase, designers would be able to enter new data to be used during the stage for the synthesis of design solutions. They would be able to store new data with each new work and have access to those which were used previously. Navigating in the system would help organize the library of references they have stored in their minds. Concepts and schemes that designers have forgotten about would easily be recovered, reorganized and reapplied. Since the database would constantly be worked on by users, during the research process, they would know how to identify concepts and schemes more efficiently in the hierarchical structure. This prospect is completely different from research normally conducted through books on renowned architects, the Internet or with any other form of conventional data storage. In those situations, designers waste time not only reorganizing the references, but also rearranging and hunting for the precedents again. Therefore, a research system like the one presented in this paper would not only be beneficial for teaching, but would also result in a significant improvement in information management during the design process, also at the professional level.

Acknowledgments

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