Knowledge Integration in Civil Engineering: a model for information structure

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Abstract - **This paper describes the issue of knowledge integration in civil engineering, proposing a knowledge structure to help students to perceive the connections among disciplines in civil engineering. The case study was made with the Course of Civil Engineering of Universidade Federal de Juiz de Fora. Recent survey conducted within the civil engineering courses in Brazil showed that there is lack of integration among the several disciplines that embody the civil engineering specialty. The purpose of this paper is to present a knowledge model that integrates materials and building processes, attaching them to the stage of construction of an ongoing building project. The ISO standards regarding classification of information for the building industry were used as a basic reference to create the terminology of the proposed structure. The model integrates documents, building elements, building processes, management processes, classified materials and working instructions and is depicted using bi-dimensional diagrams to offer a visual understanding of the relations established. An example involving the design and installation of a door in a typical building was created and presented to a group of civil engineering senior students. The model allowed the students to figure out the network of relations linked to a single element and make them identify contextual knowledge in a body of known and organized knowledge for future use. The results of this work confirmed our prior assumptions regarding the lack of integration of the civil engineering curriculum. It has proved the need of a controlled vocabulary in the engineering course in order to reduce ambiguity and errors. The application of the model allowed participants to structure contextual knowledge, permitting them to share their individual's tacit knowledge and proceed knowledge acquisition through the understanding of all the universe of activities that are linked to each building element.**

Index Terms – civil engineering, information structure, integration, knowledge. design knowledge

INTRODUCTION

This paper describes the issue of knowledge integration in civil engineering, proposing a knowledge structure to help students to perceive the connections among disciplines in civil engineering. The application of the model allowed participants to structure contextual knowledge, permitting them to share their individual's tacit knowledge and proceed knowledge acquisition through the understanding of all the universe of activities that are linked to each building element.

A progressive process of construction going back to data can define knowledge. Data is a set of symbols perceived by a person transformed to information in the interpretation of what is perceived. In this way, information is data with meaning. Thus, information is structured data with a semantic content expressible by natural language. Information is thus data with a meaning visible or understandable, something shareable and immediately usable by human beings based on their knowledge.

Engineers and architects use two types of knowledge when creating new products: procedural and declarative knowledge. The first one is a type of knowledge expressed by procedures in organizational life, while declarative knowledge refers to descriptive knowledge represented by equations, logical relations, or agents in new programming languages.

Explicit or declarative knowledge is easily shared whereas tacit knowledge is highly personal. Moreover, we would also distinguish between tacit knowledge that can be made explicit and tacit knowledge that cannot be made explicit, even if this later can be shared in a community of practice. This is the case of many handling skills in many craft jobs, and is also the case in teaching architecture and engineering by assigning projects to the students.

Context is an important issue in a number of domains, especially when investigating learning processes. From an engineering point of view, context can be seen as the collection of relevant conditions and surroundings influence that make a situation unique and comprehensible. A person doing a task normally identifies which knowledge is relevant to do his job in his repertoire, i.e., the set of knowledge pieces accumulated along his working life [1].

These knowledge pieces, which judged related to a specific step of task accomplishment, constitute the contextual knowledge; and within a project, a part of the contextual knowledge is invoked, is structured, and situated according to a given focus, thus reducing the universe of a search.

When a design task is assigned to a student, his perception of the contextual knowledge is not straightforward, i.e., grabbing relevant knowledge from his repertoire is not easy for a novice. Design knowledge is built up incrementally on the basis of experience [1]. The ability to deal with new cases is derived from former ones as an inductive process of learning. Inductive inference techniques, i.e. chunking, abstraction/specialization and simplification are particularly relevant to design knowledge acquisition.

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Design tasks are linked to procedures, generally used by engineers as frames to construct a genuine strategy tailored to the specificity of a given situation. In this sense, there are some planned collective activities in design that are adapted for each case, or each design step, no mattering the nature or the type of the project [1].

The issue of knowledge integration is then the main challenge in teaching design to students and it is the focus of this paper.

This work presents a knowledge model that integrates materials and building processes, attaching them to the stage of construction of an ongoing building project, allowing students to crossing the border between disciplines as their perception of relevant knowledge is not straightforward, needing assistance to surpass these difficulties.

This structure is based on the process model [2], which presents construction objects organized by facet classification. Initially, the structure was used in the organization of the explicit knowledge found in the *Sistema de Qualidade da Empresa de Edificações* (The Building Company's Quality System) documents.

SURVEY BACKGROUND

In general, in Civil Engineering graduate courses the acquisition of knowledge has taken place in a disintegrated way, without a holistic view of its context of application. As a result, the professional ends up reproducing in practice the way he was taught during his academic formation.

Last-year students were chosen to participate in a survey in order to check the knowledge they have on the construction process of buildings. Students were presumed to have already acquired much of the knowledge required for their professional activity.

The survey was made with the Course of Civil Engineering of Universidade Federal de Juiz de Fora (UFJF). The course is divided into semesters and the disciplines are distributed within four Departments: Civil Construction, Structural Engineering, Hydraulics and Sanitation, and Transportation. The student can emphasize his studies in any one of these areas against the conclusion of a minimal number of hours. Disciplines related to the construction process are basically found in the Civil Construction Department: Construction of Buildings, Construction Materials, Construction Planning and Control, Construction Management, etc. The former ones are mandatory and the latter is elective, i.e, the student will only enroll in it if interested.

The data collection tool used was the questionnaire. Sixty-five last-year students were interviewed throughout 2003 and 2004. Students were invited to participate in the survey. However, as this was not an activity included in the discipline, some opted out of answering the questionnaire.

For students, knowledge acquired in College is complemented with that obtained in internship programs. The activities developed in both of these settings provide the student with a view of the construction process, with its required materials and necessary services.

The student survey showed a variety of concepts for the same term. The confusion arising from these terms reinforces the lack of a consensus regarding terminology. For example, the term <u>management</u> is used as a synonym for Activity, Administration, Control, Method, etc.

Most students consider mastering specific technical knowledge crucial for the construction manager in his professional field besides market knowledge where the company operates. This includes knowledge especially in Integration, Time, Cost and Project Quality Management. On a lower scale, the need for knowledge in risk management and Human Resources is also identified. The latter, despite not being considered a "technological" area in Engineering, is now being approached with greater intensity. This is due to the increasing interest in the development of the competences of a company's collaborators. This movement seems not yet felt by students. Another point that raises special attention is related to communication management. Emphasis in this area has also been growing recently, since it can provide a better flow of project information. Its importance, however, seems not yet clear for the future professionals.

As for the interviewee's mastering of the several areas mentioned, they range mostly from regular to good. Neither of them considered to have excellent mastering over any of the areas surveyed. Although 58% of the students answered they master project integration, only 37% master project scope, which seems inconsistent once integration is based on the knowledge of what must be integrated.

PROPOSED MODEL

Organizing knowledge is arranging it according to a classification criterion. In its simplest form, classification is the arrangement of entities in groups or classes based on their similarities [3]. Still according to this author, classification is both the process and the result of the judiciously arranged representation of the elements or cases of a universe. The rule for the creation of a classification is that it should be exhaustive and mutually exclusive [3]. In order for the classification to be exhaustive, all terms belonging to a group must be attributed to a class and, for it to be exclusive, each term must belong to only one class.

The first difficulty on structuring knowledge in civil construction is the lack of a classification system which is of common consent in the field, and the non-existence of a national norm for the classification and organization of information in this area. The structures used by classification systems, in general, are based on a hierarchical tree, such as those used in budgeting systems, which facilitates the user understanding of its logics, but whose rigidity makes it difficult for the insertion of new elements. One problem found in these structures is that objects can be classified in more than one class, on account of the approach considered. Such is the case, for example, of metal bathroom accessories that are not classified as metal (material), but included in the bathroom accessories class (its purpose), thus contradicting the condition that states that each term should belong to only one class.

Another option for knowledge classification is the use of facets, a set of characteristics that can be applied to the universe under analysis. Facets are, therefore, exhaustive groups with similar quality properties. These groups are formed with terms defined by relevant properties for the classification. The matrix association between the elements of each facet results in the description of the object of the universe in study, and the use of all facets is not necessary. The faceted classification was developed with the purpose of creating libraries for term systematization in areas of knowledge.

The use of facets is closer to the classification of construction-related information models found in the norm ISO [2], which presents a relational structure for the information in the construction industry. This norm is a more condensed and revised version of the other norm ISO [5], which considers the basic concepts of classification in the construction industry to represent the properties of interest to the project process, to the construction process and to the management process. The categories presented by this norm are: *facility*, *space*, *element*, *work section*, *construction product*, *construction aid* and *attribute*. This norm works with the concept of process and recognizes the benefits of using modeling methodologies in the classification work.

Reference [2] identifies three classes of objects from a basic construction process model. These are grouped according to their function in the production process as:

- **Resources or entries**: construction objects used in a construction process to reach a construction result. They can be CONSTRUCTION PRODUCTS, COMPLEMENTARY RESOURCES (EQUIPMENT), CONSTRUCTION AGENTS AND INFORMATION RESOURCES.
- **Processes**: means by which the construction resources are transformed into construction results. They are related to the DIRECTION CONSTRUCTION AND MANAGEMENT, WORK METHODS and CLASSES RELATED TO THE CONSTRUCTION PROCESS – such as LIFE CYCLE and INFORMATION CATEGORY (as designed, as demanded, as built).
- **Results and by-products**: construction objects created as a result of one or more construction processes making use of resources. They include CONSTRUCTION, COMPLEX CONSTRUCTION (group of constructions), SPACES AND SPECIALIZATION OF BUILT ENTITIES (CONSTRUCTION ELEMENTS, DESIGNED ELEMENTS AND RESULT OF CONSTRUCTION ACTIVITIES).

STRUCTURE FOR THE ORGANISATION OF KNOWLEDGE

I.Facet Select

From the concept of process [2], the necessary facets were defined for the classification intended for Construction Materials and Services.

Reference [2] shows construction materials in the *resources* class. However, this paper does not use a table for construction materials (*construction products,* according to ISO) on account of the previously mentioned difficulties found for their hierarchical classification. The facet classification was then chosen. Thus, the facet called Attributes (*properties and characteristics,* in the ISO) is used where the materials are identified by the attributes that qualify them, in this case, the Basic Material they are made of. This facet includes the objects in groups according to their physical characteristics. Later, new attributes may be considered.

Still in the *resources* class, the facet called Documents, corresponding to the *information resources* (according to the ISO), considers the documents required by the Quality System.

Reference [2] includes the Execution Processes (*work methods,* according to the ISO) and Management Processes (*direction and management*, according to the ISO) in the *processes* class. The Management Processes considers those processes directly related to the Quality Management and referring to Material Purchasing, including the qualification of suppliers.

Finally, the facet Construction Elements is used for the ISO's *results* class. The facets considered are shown in Chart 1 below.

CHART 1
FACETS CONSIDERED

Reference [2]		This study	
Resources	Construction Products Information Resources	Attributes Documents	Basic Material
Processes	Work Methods Direction and Management	Processes	Execution Managing
Results	Construction Elements	Elements	Construction Elements

II.Recovery of the Explicit Knowledge present in the Building Company

The Small Construction Company, despite showing little formalization of its procedures, has a variety of documents required for its activities, such as contracts, invoices, worker records, etc, which reveal they have explicit knowledge. Under this focus, the best documented area is that of Quality Systems.

On implementing a Quality System, the company must prepare a list of controlled execution services which affect product quality containing, at least, the 25 services demanded by SiAC (*Sistema de Avaliação da Conformidade de Empresas de Serviços e Obras da Construção Civil* – Conformity Evaluation System for Civil Construction Companies). Work instructions are created for the controlled services in order to describe the process that must be followed for the execution of each service. Service Inspection Forms are then created after each service has been executed.

From the list of controlled services each company must create a list of materials that are used in these services, including at least 20 items, which may affect quality, both in the services and in the final product, the building. For each controlled material, there is a Materials Specification, an Inspection Criterion and a Receipt and Manipulation Test as well as a Storage, Packaging, Preservation and Delivery criterion all created in accordance with the Technical Norms. Material Receipt Registration Forms are filled in after each material has been received on site. A Supplier Qualification Certificate is issued for each supplier.

As for the management processes, this study considered the Purchasing and the Supplier Qualification Process. For the suppliers, the records produce a List of Qualified Suppliers as well as their Qualification Certificates.

III. Proposal for a structure

Classification tables were created after the facets had been defined and the documents analyzed.

The first structured table to be created was the Document Table. The classification chosen for the documents originated from the list of documents produced by the company in accordance with the criterion of organization used in the quality-related technical documents (Chart 2).

CHART 2
DOCUMENT CLASSIFICATION

LEGAL OR REGULATORY DOCUMENTS
1.Norms
Brazilian Technical Norms
2. Quality System Documents
Specification of Materials
Inspection Criteria and Receipt and Manipulation Tests
Material Storage, Packaging, Preservation and Delivery Criteria
Purchasing Process
Supplier Qualification Process
Execution Process (Work Instructions)
MANAGEMENT DOCUMENTS
Quality Management Documents
Supplier Qualification Certificate
Material Receipt Registration Form
Service Inspection Registration Form
Non-Conformity Treatment

The Processes tables were the next to be investigated. In order to make the Execution Processes table, it was necessary to search the literature so as to check how the services are organized. Reference [4], [6] and [7] tables were used as a comparison. The former was used because it shows a facet classification, similar to the one used in this study. The two other references were also analyzed in spite of using a hierarchical classification for the following reasons: they are used by the Federal Government in public services [6], and it presents a widely known budgeting structure [7] (through its Unit Price Compositions). The table of Execution Processes originated from this analysis.

The Management Process table comprises only two processes: Purchasing and Supplier Qualification.

The Materials Table was the next to be investigated after the Document and Processes table had been created. Construction materials are classified by the Basic Material they are made of. For the company's controlled materials the association is directly made between the construction material and the Basic Material, except for circuit breakers. This material presents a specific form and function and is, therefore, classified as an element. The basic material tree was composed as follows: Steel, Sand, Mortar, Stones (aggregates), Lime, Ceramics, Portland Cement, Concrete, Fiber-cement, Gypsum (Plaster), Wood, PVC, Glass.

The Construction Elements tree was the last to be created based on the fact that the elements are composed of materials applied to a built system or entity according to an execution process. Initially, this table was created from the execution processes.

The use of terms and concepts was needed in the creation of all the previous tables. Although it is not the object of this study to establish a terminology for the construction area, establishing terms and concepts is necessary so as to allow for the design of a consistent structure for the classification of the proposed knowledge.

The corresponding terms, found in the ABNT norms, in construction dictionaries available on the Web and the reference literature, were listed based on the previously arranged Elements tree. The terms and concepts were related and the Elements tree thus obtained was tested by experts. They were asked to indicate or even to insert the terms and concepts which would suit them best. Three professionals, working in the Construction Industry in the city of Juiz de Fora, took part in the test.

The object of the survey carried out with the professionals was to list the terms and concepts that could be used both in academia and in professional practice. These discussions helped test the structure since not only terms and concepts were analyzed but also the appropriateness of each tree. The test allowed adjustments to be made in the table presented to the professionals, resulting in the table currently in use.

The terms for the Execution Processes originated from the Elements tree. The choice of the most appropriate terms for the Basic Material and Document trees was the responsibility of the first author of this paper.

Finally, it is important to say that this study does not intend to develop the entire tree for each facet, but only the necessary part to demonstrate that the knowledge recovered in the company can be sustained in it. A partial example of the structure is shown in figure 1 while the final structure can be checked in [8].

EXAMPLE OF A BUILDING ELEMENT: DOOR

A case was chosen as an example to the use of the Structure for the Organization of Knowledge: the Door. First, the example-related Quality System documents involving service and materials were identified.

As for the service, the List of Controlled Services contains the Work Instructions for Doorframe Installation and Door Installation, and as for the material, the List of Controlled Materials contains Wooden Doorframe and Wooden Door.

Next, the classes containing information on the case study were identified in the facets, which in this case are comprised of Processes, Elements, Basic Material and Documents.

The Document class presents the Technical Norms (for wooden doors) in the Regulatory Documents. The Quality System Documents contain the Materials Specifications, Inspection Criteria, Receipt Tests and Criteria for Wooden Door and Wooden Doorframe Manipulation and Storage. It also contains the Execution Process – Work Instruction (Door Installation and Doorframes Installation).

The Purchasing Process and the Suppliers Qualification Process are processes in the company which are applied to all materials, among them, the Door and Doorframe here in considered. They are classified in this study, but the documents are not presented since this would require authorization from the company to make them available.

The Documents related to Quality Management contain the Suppliers' Qualification Certificates, the Material Receipt, Services, and Non-Conformity Treatment Cards. The former doesn´t exist for this case and the remaining documents, related to Material Receipt, Services and Non-Conformity Treatment, are classified but not shown.

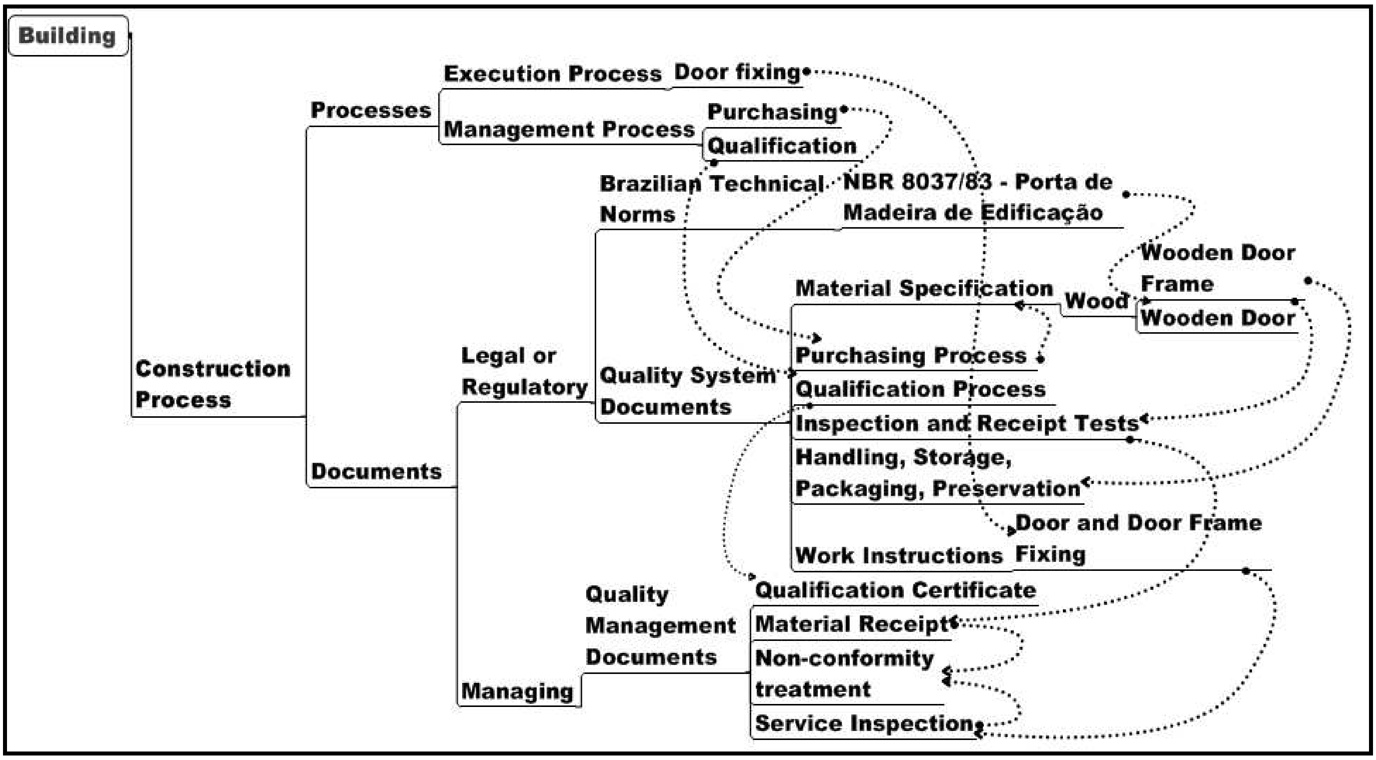

FIGURE 1
EXAMPLE OF APPLICATION OF THE STRUCTURE

From the graph display of the Structure for the Organization of Knowledge shown in Figure 1 we can infer that the WOODEN DOOR:

- Must meet norm NBR-8037/83 – Porta de Madeira de Edificação.
- Must be installed according to the execution process for door and window frames in the Work Instructions (Doorframe Installation and Door Installation).
- Must be purchased according to a Purchasing Process adopted by the company and meet the recommendations in the Purchasing Process document. It interacts with suppliers who must be qualified according to the Suppliers Qualification Process also contained in the document.
- The Door and the Doorframe are purchased according to the specifications described in the product WOODEN DOOR and WOODEN DOORFRAME, and must meet the criteria of Inspection and Receipt, as well as the criteria for manipulation and storage.
- After the Door and the Doorframe have been received, the material receipt card is filled in upon checking the product conformity. After installation, a service inspection card must be filled in registering the service and presenting a possible non-conformity. Should a non-conformity be found, the necessary measures must be taken to correct it.

Finally, we can state that the structure proposed for the organization of knowledge, based on the Document, Process, Element and Basic Materials trees for the Small Construction Company, has made it possible for Materials, Services and Suppliers to be related. The starting point was a real-life example based on the quality documents surveyed at Company "A".

TESTING THE MODEL

After the Knowledge Organization Structure was finished, it was tested with a group of last-year engineering students at UFJF who already had a previous knowledge on the subject. The test was not concerned with statistical validation. The purpose was to check the applicability of the structure faced with the proposed knowledge integration.

The 22-student class was divided into groups of 2 students. Each group of students was given the list of controlled materials and services, according to SiAC and a list of technical norms. Using one Service (chosen from the list of controlled services) the students were asked to identify:

- The sub-processes (if appropriate).
- The most representative materials for the process execution.
- The technical norms the materials should abide by.
- The concepts for some of the terms used.

Nine groups turned in their answers. There was a clear association of the Service to the material used as well as a clear association of the materials to the norms that regulate them. Only three of the controlled materials were not associated to their corresponding norm.

Another observation was related to the terms used in the answers. Although the students received a list of materials (list of controlled materials), their answers showed Plywood Board and Plywood Sheet (referring to the same material). The same occurred with industrialized brickmortar and grout mortar. As for the processes, there was a tendency in keeping the terms used in the list of services.

Although terminological rigor is not required from the students, in some cases, this situation can become conflicting. For example, the concept given for Tiling, in which one group called it a stage and the other classified it as a material, although they were both practically stated with the same purpose. This is a similar situation to that existing in some ABNT norms. These results point to the necessity of working the terminology and the concepts with the students more intensely.

It is important to understand that the object of the exercise was to check the question of integration. It was not expected that, within only one class time period, the new concepts presented would be learned with terminological rigor. The purpose is to make the meanings of the concepts understood.

Finally, it was possible to see that the structure made the Construction Process clearer as well as identified the importance of a greater conceptualization of the terms used in this area of knowledge so as to avoid mistakes.

CONCLUSION

The task of organizing the information in the building field is difficult due to the non-existence of a national classification system with a general consensus, nor is there a national norm for the classification and organization of this information. As a solution to this problem, the structure of the existing (hierarchical and facets) classifications was approached and the choice was made for the classification by facets.

The structure proposed for the organization of the knowledge based on the Document, Processes, Elements and Basic Materials trees for a small building company has enabled the relation to be made among Materials, Services and Suppliers. A real example was used based on the quality documents obtained from one company. Later, other documents used by the company may be included. This will allow for the registration of experiences.

The results of this work confirmed our prior assumptions regarding the lack of integration of the civil engineering curriculum. It has proved the need of a controlled vocabulary in the engineering course in order to reduce ambiguity and errors. The application of the model allowed participants to structure contextual knowledge, permitting them to share their individual's tacit knowledge and proceed knowledge acquisition through the understanding of all the universe of activities that are linked to each building element.

In other hand, the organized and integrated knowledge originated from a classification structure can work as a professional habilitation/updating tool, capable of integrating the knowledge of the area under consideration. Moreover, it can contribute to the strengthening of the technical history of the company and work as a channel to disseminate this knowledge to its collaborators.

ACKNOWLEDGMENT

CAPES - Fundação de Aperfeiçoamento de Pessoal de Nível Superior for the D.Sc. grant given to the first author of this paper. This research work was developped at GEPRO – Grupo de Ensino e Pesquisa em Gestão do Desenvolvimento de Produtos Industriais attached to the Program of Production Engineering of COPPE/UFRJ.

CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico for the research grant given to the second author of this paper.

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