An image based information retrieval system for engineering projects

Renata Maria Abrantes Baracho
School of Information Science
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil
renatabaracho@ufmg.edu.br

Beatriz Valadares Cendón
School of Information Science
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil
cendon@eci.ufmg.br

Frederico Fonseca
College of Information Sciences and Technology
The Pennsylvania State University
State College, USA
fredfonseca@ist.psu.edu

Lidia Alvarenga
School of Information Science
Universidade Federal de Minas Gerais
Belo Horizonte, Brazil
alvarenga@eci.ufmg.br

***Abstract* – Today there is a great amount of information in the form of engineering projects. The difficulty in retrieving visual information contained in engineering projects in various contexts in which engineering designs are used as inputs in decision making is an area of major concern. Current methods of retrieval do not satisfy the demand for the rapid and precise location of information contained in large sets of drawings. This is because the projects are retrieved through the utilization of codes and keywords that only partially represent their content. This paper addresses this problem by proposing an image based information retrieval system for engineering projects. The article presents a conceptual model, a classification scheme and a prototype of an information retrieval system (IRS) for engineering projects that uses a key-image to retrieve a document. The prototype was tested and validated in a case study conducted at the Military Fire Department of the State of Minas Gerais (MFDMG), Brazil. The system proposed would positively impact services and decision making in areas such as infrastructure (sanitation, energy and roads), safety, healthcare and education.** [1]

Information retrieval, image retrieval, engineering projects, information retrieval based on image visual content.

I. Introduction

The motivation for the current study was the difficulty in retrieval of information in engineering projects required for decision-making as well as the need to achieve greater efficiency in the process of encountering information in large sets of drawings. The current information retrieval systems (IRS) for engineering projects use textual data to index and retrieve project files and do not normally consider image data. Information retrieval frequently depends on someone who participated in the project and is lost when that person is no longer part of the process.

To address this problem, the current research had the objective of building a model for automated indexing and retrieval of engineering projects, considering visual content and the use of key-images for retrieval. The paper presents, briefly, the theoretical basis, the conceptual model and the classification scheme, already introduced by Baracho and Cendón [1], and expands this previous publication by presenting the description of the development of the prototype which implemented the model. The present paper also describes the case study conducted at the Military Fire Department of the State of Minas Gerais (MFDMG), Brazil through which the developed system was tested.

The literature review discusses research on organization and retrieval of images in information science and computer science. The state of the art indicates a gap in research on image retrieval with the presence of two distinct lines: information science focuses on retrieval based on textual description of images while in computer science retrieval is based on visual content. In the prototype developed efforts were applied to bring together knowledge from these different areas resulting in a system which integrates concepts of information and computer science as well as engineering.

In the system proposed, to build the metadata database, a human indexer interprets and classifies the projects into three categories (type, process and form). These are used by the system to select a specific set of visual metadata (icons) which are automatically located in the drawings. Next, these icons are used to automatically index the documents. The drawing files and visual metadata compose the database. For retrieval, the user is presented a menu of icons for key-image selection. The system, then, finds all the drawings containing the key-image selected, and displays them highlighting the hits.

A case study with the Military Fire Department of the State of Minas Gerais (MFDMG), Brazil was conducted which used corpus of 332 technical drawings of safety projects. The research results showing 98.7% retrieval rate for files that contained images similar but not identical to the key-image, proved the efficiency of the system.

II. Theoretical and Conceptual Base

The literature review led to two different approaches. The first, based on the concepts and foundations of information science, uses descriptive data to index and retrieve information in images. The second, based on concepts and foundations of

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computer science, achieves content based information retrieval through the graphical properties and shape of the image. According to Enser [2], Heidorn [3] and Smeulders et al. [4] there is a gap between these two approaches which must be filled in the search for innovative solutions for image retrieval. In the current study, these two concepts were merged and used in the creation of a model, a classification scheme and a prototype of an IRS for engineering projects.

In short, there are two distinct lines of research for the retrieval of visual information. One line considers the semantic understanding of the image and the determination of the concepts that represent the documents. In this line, the description of the image is done through text. Another line of research considers the syntactic processing of the image, seeking to define the contents and properties of existing symbols and icons through digital processing of the image.

A. Organization and retrieval of information science

In information science, subject analysis, definition of access points, interpretation, categorization, classification and indexing of documents are used for organization and retrieval of information. According to Lancaster [5], retrieval of information is the process of searching within a collection of documents to identify those dealing with a particular subject. One of the problems in retrieval is the definition of access points to a database of electronic documents containing text, images and different media (Hjorland [6]). The retrieval process is complete when the user is satisfied with the results of his search. In the case of engineering projects, the definition of the concepts that represent the document is done through human observation and interpretation. Each person uses his or her own knowledge when reading a document and makes his or her own interpretations, which are personal and subjective.

B. Organization and retrieval of computer science

In computer science, content based information retrieval is achieved by detection of the image features as well as identification and classification of its visual characteristics based on color, texture and shape. Content-Based Image Retrieval systems (CBIR) usually use algorithms to test the whole image or part of it to identify forms similar to the images searched for. A retrieval system based on the image involves the determination of the characteristics of the image and, adopts the following steps: detection of visual characteristics of the image based on color, texture and form and classification of the visual characteristics of the image. These are used to feed the database and, later, to retrieve the image desired. This last phase is attained through comparison and detection of similarity. To begin a search, the user selects the characteristic he is looking for and defines a similarity measure. The image searched for can be defined by the user or obtained from an example as shown in Fig 1. The system checks the similarity between the visual content of the key-image and the database images. Concepts and techniques of digital image processing are used for detection based on the shape of the object. According to Gonzales and Woods [7], the term image or monochrome image refers to the two-dimensional function of light intensity, f (x, y), where x and y denote spatial coordinates and the value of f at any point (x, y) is proportional to the brightness (or gray levels) of the image at that point as shown in (Fig. 2b). It can be considered as an array whose indices of rows and columns identify a point (Fig. 2a) in the array. The corresponding value of the array identifies the gray level at that poin
t.

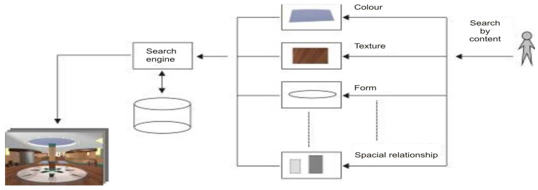

Figure 1. Example of search by colour, texture and form.

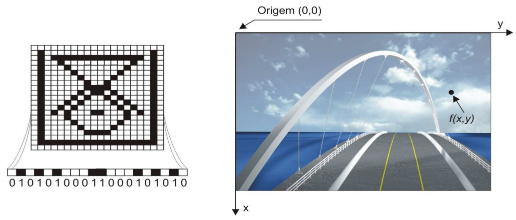

Figure 2. (a) Image matrix. (b) Axes representation digital image.

Zachary [9] emphasizes that the fundamental aspect of the visual information retrieval systems is the determination and representation of a visual feature that effectively distinguish between pairs of images. For Hède [10] retrieval by picture similarity considers image variation which enhances the level of information retrieval.

C. The Engineering project

This section presents an overview of the object of this research which is the document and engineering project. There are specific issues in the organization of information in engineering projects. Each branch of engineering produces a set of projects needed for the construction of an object. Engineering projects can be of various types such as agronomic, aeronautical, agricultural, food, environmental, civil, computer, economical, electrical, structural, forest, mechanical, mechatronical, mining, naval, production, chemical, sanitary, safety, software, telecommunications, transportation, among others. Each project type has its specificities and characteristics, which determine a series of subdivisions. Civil engineering alone involves the architectural, structural, hydraulic, electrical, fire fighting and prevention, air conditioning projects, among others. The engineering/ architectural project is usually developed in well defined steps executed in a linear sequence, which include preliminary design, executive project, detailed design or presentation project. Each step in the development of an engineering/ architectural project is composed of a group of documents that represent, in different views, the object to be built. The engineering project is a set of standardized documents/technical drawings (Fig. 3) needed for the execution and representation of engineering works. The set of graphical records is the graphical expression which aims at representing form, dimension and location of objects, according to the different needs of the many branches of engineering and architecture. The drawing is a code for a language established between the sender (professional from the project field) and the receiver (reader of the project), enabling one to understand it. Its interpretation requires knowledge both from the sender and from the receiver. In order to interpret a project, one needs to build a mental visualization based on an abstraction to understand a spatial form from a flat representation. This process, called spatial vision, depends on the knowledge and perception of the human being, because to understand a spatial form means to build a tridimensional model in the mind based on the observation of two-dimensional drawings. The document file is a composite of geometric representations contained in one part or all of an engineering project. The set of documents, through the different views, provides a representation for the implementation of the project. The icons present in the technical drawing allow inferences and conclusions about the project as a whole, defining the type of project, the process and the form.

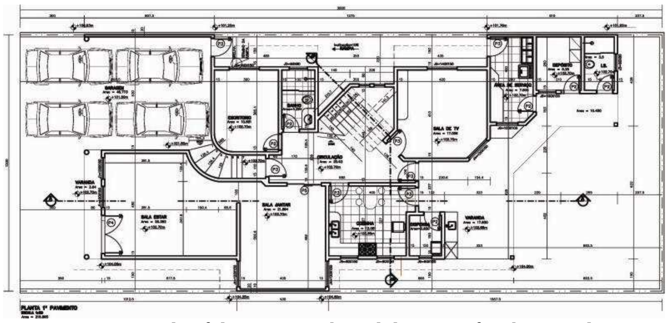

Figure 3. Example of document/technical drawing of architectural project.

The standardization of documents is an important step in the creation of a graphical language. Technological progress and the standardization of drawings made possible the creation of computer aided design (CAD) software which is now globally used for project development. The information contained in the draft can be enhanced by the explicit semantics or meaning of the common syntax of the symbolism.

To increase the performance of CAD software, it became necessary to develop libraries of icons. The libraries, used in project development, consist of a standard set of icons. Typically, they represent objects that are repeated in the same document or in different project and their definition depends on the context. The same library can be used in different projects, institutions, cities and states, and each institution usually has its own. Fig. 4 shows an example of a library of icons.

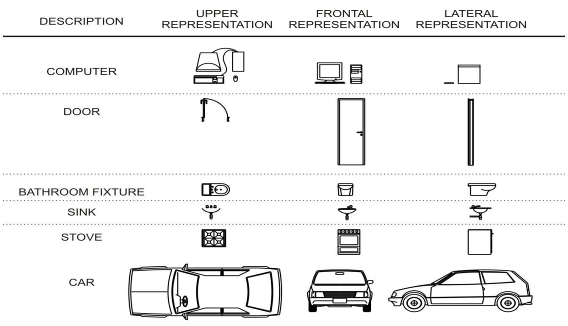

Figure 4. Example of a library od icons.

III. CONCEPTUAL MODEL

The model proposed in the current paper considers human analysis and interpretation of the image as well as automated processing of visual content for the definition of the metadata to be used for retrieval of engineering projects.

Through the analysis of how interpretation of engineering objects takes place, a model to understand engineering drawings was defined which joins syntactic and semantic representations of the drawing. Considering the cognitive aspects for image interpretation, when a person observes an engineering project, he or she creates a network connection in order to identify symbols and make inferences on the drawing. With specialized level of knowledge, the user builds up the mental model of what is represented in the drawing.

This process happens at the moment the project is interpreted. Systematizing this process, the model presents the interpretation of the project in two steps. The first one involves iterative understanding of the drawing, the determination of its subject on the semantic level and its analysis, in order to define what it represents. The second is the syntactic interpretation of metadata, with the definition of administrative, technical and visual metadata of the drawing, as shown in Fig. 5.

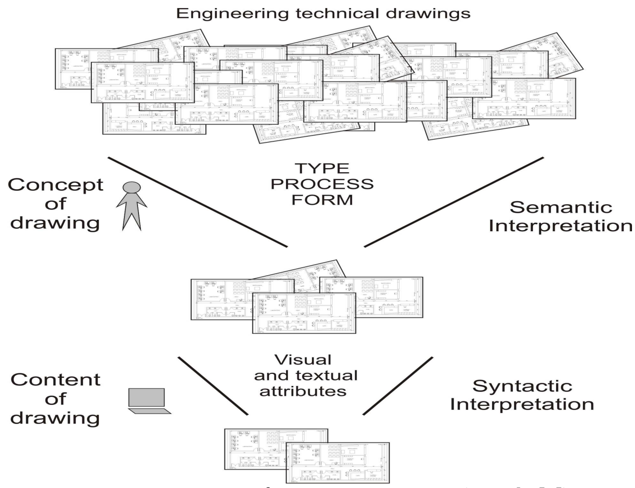

Figure 5. Two steps of project interpretation (Baracho[8]).

Semantic interpretation takes place by means of the inferences made when a human subject observes the project and mentally defines the object depicted. This enable the conception, through spatial vision, of the object represented. For example, from the reading and identification of the icon that represents a door, we can visualize the connections between the areas separated by that door, the direction of people flow, and the number of rooms in a building. From the reading and interpretation of the icon representing a computer, we can conceive that the room where it is located is destined for the use of computers and could be, for instance, an office or a lab. Interpretation of the image leads to the description of the image and to the definition of its concepts. For example, the recognition of an icon referring to a car leads to the understanding that the space where it is located is conceived to be a garage and is capable of sheltering, for example, four cars.

Syntactic interpretation takes place through the reading of icons present in the document. By means of syntactic interpretation one can assess the attributes present in the project. In this phase, the attribute is the geometric representation of a symbol and is not contextualized. An attribute of a door, in top view, is simply the representation of a line and an arch. The icon of a door presents different geometric representations according to its position in the project. Through syntactic interpretation and the recognition of icons we obtain the definition of the image content. We can interpret the icons by themselves, without considering their context. For example, a computer represented in upper, frontal or side views (attribute) leads us to the object computer (content).

IV. CLASSIFICATION SCHEME

The classification scheme includes the formal categories of engineering/architectural projects. In classification theory, a formal category has the property of being exclusive, so that each document can only belong to one category at the time of information organization. Thus, the classification scheme serves as a filter for the documents. The three categories present in the classification scheme proposed are: type, procedure and form.

In the model proposed here, classification starts with the interpretation and analysis of the project by a human indexer who defines textual metadata and classifies the document using the three categories: type, process and form. As Fig. 6 demonstrates, the combination of the three categories determines a specific set of icons in a table of visual metadata, which might be present in the draft. According to the classification scheme shown in Fig. 6, the presence of the icon for a door in a drawing determines the type of project (architectural), the implementation phase of the process (executive) and representation form (top view) therefore defining the icons which can be present in the document.

The three graph axes have the option ¨others¨ thus the classification scheme has an open architecture which can be extended to include other categories that are not predefined in each axis. That makes the classification scheme capable of being adapted to other contexts. Each combination of values in the three axes points to a different metadata table.

The drawings are scanned to locate, index and store the icons. Project files and their textual and visual metadata compose the database. The first step in the retrieval process is the choice, by the user, of a key-image (icon), previously stored in a table of standard icons. The key-image is stored in a PGN format. Initially, the user defines the three categories (type, process and form) which lead to the table of key-images (see Fig. 6). After selecting, in this table, the image to be searched for, the user defines the similarity rate between the key-image and the icons in the documents. Next the user defines the directory where the image will be searched for. The directory contains a set of projects which are, then, scanned in search for the key-image. Once the processing is done, the interface displays the answer set (documents) with a red rectangle around the key-images found (see Fig. 7).

The model considers a hybrid system, consisting of a textual and visual data for classification and information retrieval. The textual metadata is composed of administrative and technical metadata, and is indexed with the participation of a human indexer. Textual metadata contain data for the project that are usually used for administrative control (number, name, file, company, date, address). Technical data refer to the technical characteristics of the project and can be obtained from the stamp or label of the project (scale, use, title, district, total area, area to build). Visual metadata is composed of icons that are present in the project. The capture of icons is done automatically according to digital image processing techniques for extraction of features of form. During the research development we used two tables of visual metadata, one for the development of the prototype and one for the validation and verification stage.

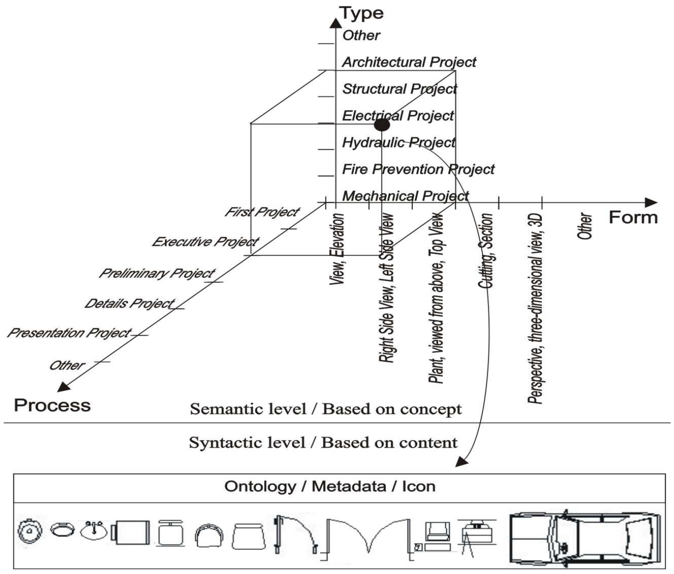

Figure 6. Classification Scheme. (Baracho and Cendón [1])

V. PROTOTYPE

A prototype was developed for the current research project, using the C programming language. For better performance, the graphic interface was developed in Java. The prototype implemented the model conceptual base in a system which interpreted, classified and indexed the image in a database. This section presents a general view of the logic and the implentation of the algorithm in the prototype. More technical details on this topic can be found in Baracho [8].

The algorithm uses a process whereby the drawings in the database are scanned to find images identical or similar to the key-image, retrieving all the documents where they are present. Next, the interface of the prototype displays the documents retrieved, marking the hits with a red rectangle as shown in Fig. 7. The central idea of the algorithm is to detect, within a larger context, shapes similar to a pre-determined shape.

At the end of the process, the system shows a window with statistical data for the search (processing time and hits). The algorithm scans the drawings for any image identical or similar to the key-image according to the three basic graphic computer transformations i.e. change in scale, rotation and mirroring. Rotations of 0°, 45° and 90° were defined. A rotation outside this range in another quadrant is an abstraction of rotation from 0°, 45° and 90° and the algorithm is able to automatically recognize this abstraction at 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315° and 360°. The algorithm also recognizes the three forms of mirroring: vertical, horizontal and vertical to horizontal simultaneously.

The prototype requires that the user determines a scale factor. Different scales are accepted despite the implication in greater computational processing. Another factor that influences the performance of the prototype is the similarity rate. This rate, stipulated by the user, defines the percentage of similarity between the image in the project and the key-image.

The key-image is used as a mask to scan the whole drawing. The algorithm compares the first point of the key-image to the first point of the whole drawing. If they are equal (black), it saves the position of the pixel on the counter. If not (white), it moves on to the next pixel. The mask covers the image from left to right and from top to bottom. Considering the transformations of rotation and mirror, each key-image can be in 12 possible positions. However, the algorithm considers just eight of these since four are repeated. Optimizations have been developed to improve the performance of the algorithm. The first optimization reduced the processing time by excluding blank spaces. If an area corresponding to the key-image is white, the algorithm jumps a number of columns equal to the length of the key-image. The second optimization ignores the edges of the whole image if a column or row of the key-image (mask) gets out of the area of the total image. The third ignores the spaces where the key-image was previously found. That is, if a key-image has been found in a given position of the technical drawing then this particular position will not be considered in further searches.

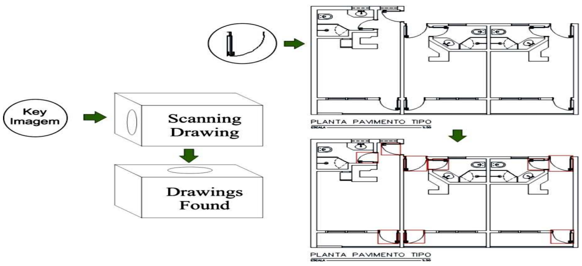

Figure 7. Principle of the algorithm. (Baracho and Cendón [1])

Fig. 8 shows the interface of the prototype. Through the option “Icones”, in the top menu bar, the key-image can be selected. In the picture, the key-image is the icon for a computer in top view. The drawings found are displayed with the hits marked with a red rectangle. The interface also shows the processing time for each drawing retrieved. To test and validate the prototype, a corpus composed of 10 engineering projects was selected and eight tests performed.

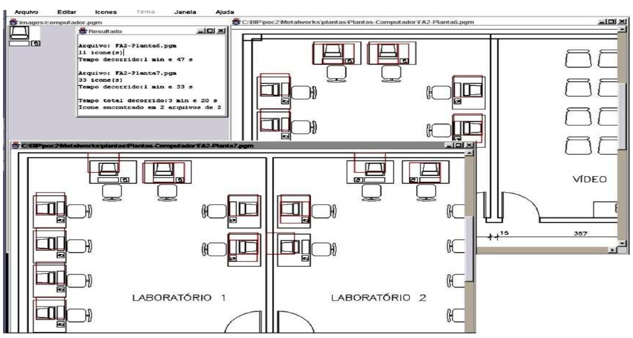

Figure 8. Interface with presentation of the images found. (Baracho and Cendón [1])

VI. Case Study - Military Fire Department of the State of Minas Gerais (MFDMG), Brazil

As a strategy for research and validation of the model and prototype, a case study was developed with the Military Fire Department of the State of Minas Gerais (MFDMG), Brazil, which used projects of fire and panic prevention.

In the MFDMG, the goal is to use the content of existing projects for buildings to plan interventions in case of an accident. Information is gathered in an online database containing the technical drawings of projects for prevention against fire and panic. The institution's archive is made up of about 30,000 projects for fire prevention and firefighting, and each project contains an average of three projects made up of plants, cross-sections, details, specifications and tables.

The corpus used for the validation of the model and prototype was composed of a set of 332 project files which represent fire and panic prevention projects. The icons that comprised the database of visual metadata for this study, shown in Fig. 9, were obtained from the table of graphic symbols in the Legislation for Security against Fire and Panic in Buildings and Risk Areas in the State of Minas Gerais.

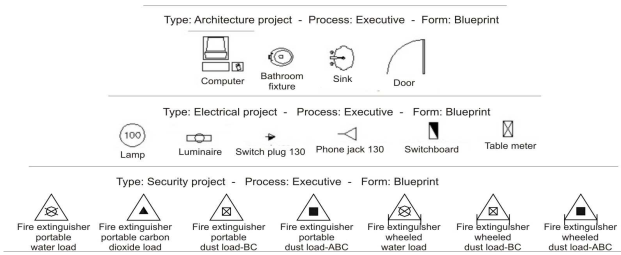

Figure 9. Graphics symbols of safety projects.

In the first development stage of the research, the prototype was customized to receive the MFDMG data. The graphic symbols table (Fig. 11) that contained the icons was implemented into the prototype. Each of the 332 drawings that comprised the corpus was edited in AutoCAD software checking for scales and patterns, and was placed in a directory. Each technical drawing was interpreted to determine the values for the three categories (type, process and shape).

For data entry in the prototype, the indexer entered the project number, the categories, filled in the textual attributes and displayed the visual attributes to be located.

VII. Results

The database, described in the previous section, was used to validate the model and the prototype. The prototype reached the objectives as it retrieved 100% of the icons in the drawings that corresponded to the key image. The test results also proved that the model reduces project indexing and retrieval time.

All 332 project files in the database belonged to the same type (fire fighting), the same process (executive project). As to the form category, they consisted of 213 plants, 74 cross-sections and 45 details. Time to manually categorize all technical drawings was 2100 seconds, i.e., it took on average of 6.2 seconds of human processing time to categorize each technical drawing while it takes, in average, 213.30 seconds of computational processing time to automatically accomplish the same task. Thus, Test 1 proved the feasibility of the hybrid system in which classification of each file was done by a human indexer. The processing time of an expert in the interpretation and classification of technical design is inferior to the time a machine would take for the same task.

The results of Test 2 show that, after the definition of the category "Form of the Project", which in this corpus comprises ground plants, cross sections and details, the algorithm presents a reduction of 34% to 84% in processing time for key-image retrieval. Thus, Test 2 validated the use of the prototype as a solution that made the proposed system feasible.

For Test 3, then number of fire extinguishers was identified in 49 files selected. In Test 3, performed with ground plants, there was a 98,7% correct retrieval rate of images of fire extinguishers similar but not equal to the key-image.

Fig. 10 shows and example of a technical drawing with the icons found highlighted in red.

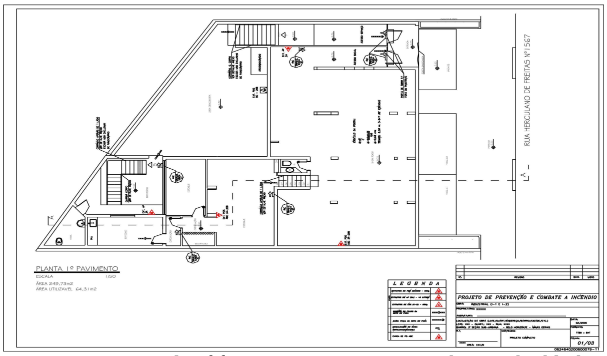

Figure 10. Example of fire prevention projects with icons highlighted

VIII. CONCLUSION

The study offers a new method for information retrieval based on visual content for architectural/engineering projects and starts an innovative line of research.

The paper presents an effective way to index and retrieve projects of engineering projects. The result is a system that adds human interpretation to automated process, links textual and visual metadata and proposes the intersection of techniques and concepts of information science and computer science. The combination of human interpretation with automated process offers great potential as it makes the system more efficient using computer processing or human participation where it is most indicated. Human cognitive processing was used in the interpretation of the drawing, determination of categories and use of the classification scheme.

The prototype shows 100% retrieval of drawings that have icons identical to the key-image. In further works, to achieve a higher level of success rate in the retrieval of icons similar but not identical to the key-image, it is necessary to implement more accurate functions that consider other variations in scale and rotation of the icons as well as lines of interference.

The validation of the model and of the prototype, through the case study in the MFDMG lead to the conclusion that the current study can be applied to the solution of problems concerning the organization and retrieval of information in engineering projects. The model proposed can be adapted to any institution which deals with engineering projects requiring only that the parameters, the specific metadata tables, the categories and the graphical symbols database are defined and adapted for each application. Examples of applications are:

How many computers are there in a building or groups of buildings? The key-image to be used would be the icon for a computer. Through this information the number of laboratories and of computers could be defined and factors such as energy consumption and maintenance staff needed, could be estimated.

How many fire extinguishers are there in a given region and where are they located for direct access in case of an emergency? The system proposed here could provide immediate response for this question, rapidly locating this data within thousands of projects which would permit more efficient action by Fire Brigades and public safety services.

Broadly, this system, proposed here, can help services and decision making areas such as sanitation, energy, roads, infrastructure in general, safety, healthcare and education.

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