Using axiomatic design to support sustainable projects at São Paulo/Brazil

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ABSTRACT: This work presents a teaching experience in the course of Planning Technology and Civil Construction Enterprises Management , in the Civil Construction Design 2 subject of, offered in the CEFET- São Paulo. The objectives of this discipline is to qualify the students to be able to identify design solutions for sustainable projects, including thermal, luminous, acoustic and functional comfort, and solutions for the structure, electric and hydraulic, in order to consider the management of the diverse fields of study information and involved professionals. For such, the classroom was divided into five groups (thermal, luminous, acoustic, functional, and structure, electric and hydraulic) and each group elaborated one project considering the axiomatic design methodology. The results were interesting because they showed to students the importance of environmental comfort and information and team management.

Keywords: environmental comfort, design methodology

1. INTRODUCTION

Design education can be made in diverse ways according to profession objectives and to the methodology that is taken into account.

In the Technology course, offered in the CEFET-SP, in design disciplines, the main objective is that the student will be able to act in the area of civil construction, learning the importance of the sustainable design, and managing diverse professional information. To achieve this objective, it is perceived the generic knowledge of the different areas that involve the project.

Methodological development and use of design principles are used to qualify students to be capable to understand the general context where design act inserts itself, and to stand out the importance of rationalizing the process of project information.

It was used the axiomatic design methods for the rationalization of the information. The classroom was divided into five groups to provide a generic vision of the sustainable questions and other fields of study, and also to provide the experience of working in teams.

2. AXIOMATIC DESIGN

There are four main concepts in axiomatic design. These are **domains, hierarchies, zigzagging** and the two **axioms**. [1,2,3]

The design problem can be divided into four **domains** generalized as shown in figure 1.

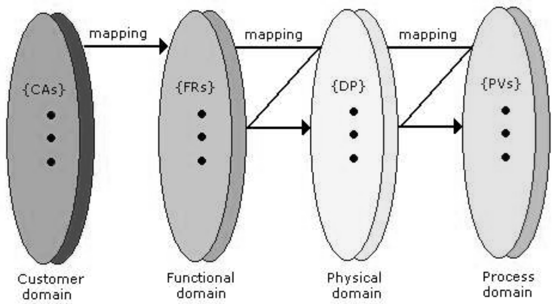


Figure 1: Domains of design [4]

The contents of customer domain are the Customer Attributes, or the benefits that customers seek, the functional domain indicates the Functional Requirements of the design solutions (FR), the physical domain contains de Design Parameter (DP) and the process domain indicates the Process Variables.

For each pair of adjacent domains, the left domain represents "what we want to achieve," while the right one represents the design solution of "how we propose to achieve it."

Decisions in one domain are mapped into the domain on its right. In our course it was consider only the mapping between functional and physical domains.

The design progresses from high levels of abstraction to level of more detail. This is represented in terms of design **hierarchy**. Beginning at the highest level, the designer selects a specific design by decomposing the highest-level FRs into lower-level FRs. This can be done once the highest level DPs are chosen. Decomposition proceeds layer by layer to ever lower levels until the design solution can be implemented. **Zigzagging** between pairs of domains describes the process of decomposing the design into hierarchies as shown in figure 2.

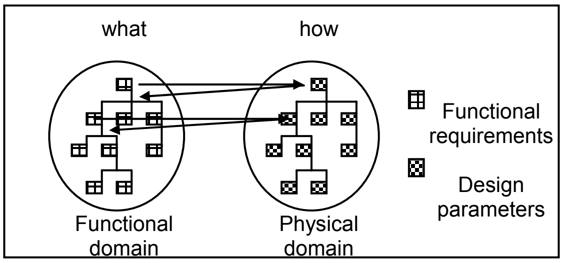


Figure 2: Decomposition by zigzagging

The mapping is represented by a design matrix (see table 1), which shows the relationships between FRs and DPs. An X or O in a cell indicates whether the column's DP affects the row's FR or not. Instead of a simple X or O, each cell can contain the mathematical relationship between the FR and the DP.

Each FR of the lowest layer of each branch is defined as a 'leaf'. The higher-level FRs is satisfied by combining the 'leaves' according to the information contained in the design matrix.

Table 1: Design matrix

	DP1	DP2	DP3
FR1	X	O	O
FR2	X	X	O
FR3	X	O	X

This design process (decomposing design into hierarchies and mapping through domains) is govern by **two axioms** stated as:

AXIOM 1 The independence axiom: Maintain the independence of functional requirements (FRs)

AXIOM 2 The information axiom: Minimize the information content.

The application of axiom 1 may be described in terms of the design matrix. There are three possible states of design matrix. These are shown in table 2.

Table 2: Design Matrices

	DP1	DP2	
FR1	X	O	FR1=DP1 FR2=DP2
FR2	0	X	Uncoupled design
	DP1	DP2	FR1=DP1
FR1	X	O	FR2=DP1+DP2
FR2	X	X	Decoupled design
	DP1	DP2	FR1=DP1+DP2
FR1	X	X	FR2=DP1+DP2
FR2	X	X	Coupled design

One can observe on table 2 that designs, which do not satisfy the Independence Axiom, are called coupled and Designs that satisfy the Independence Axiom are called uncoupled or decoupled. The difference is that in an uncoupled design, the DPs are totally independent, while with a decoupled design, at least one DP affects two or more FRs. As a result, the order of adjusting the DPs in a decoupled design is important.

The system representation use module-junction diagrams and flow diagrams. A module is defined as the row of design matrix that yields an FR when it is provided with the input of its corresponding DP. Figure 3 shows this representation for uncouple, decouple and couple designs.

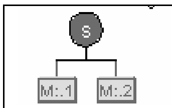
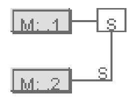
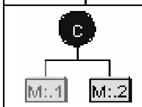
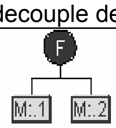
	
Module-junction for an uncouple design	Flow diagram for an uncouple design
	
Module-junction for a decouple design	Flow diagram for a decouple design
	
Module-junction for a couple design	Flow diagram for a decouple design

Figure 3: module-junction diagrams and flow diagrams.

In an uncouple design, since the child FRs are independent of each other, their parent FR is satisfied by combining all outputs of its child modules in any random sequence, the summation junction "S" represents this fact. When the design is decouple, their parents FR is determined by combining the child modules in a given sequence indicated by the design matrix. This is represented by the control junction "C". For a couple design, which violates the Independence Axiom, the junction "F" requires that the output of the right-hand side module be feedbacked to the left-hand module, requiring a number of iterations until the solution converges. The junctions define how the modules should be combined at each level of decomposition [1].

A main module is defined as a module that contains all the junctions of all levels. A system has one main module and *n* modules corresponding to *n* FR leaves.

3. CASE STUDY

The project developed in the discipline of Civil Construction Design 2, in the 1st semester of 2005, had as subject the State High Schools, because a standardized documentation of environments exists and facilitates the development of preliminary study. The access to the design models and documentation of the State Foundation for the Development of Education (FDE) is easy and there is the possibility to visit the chosen school.

Initially the division of the classroom into five teams was made: 1)functionality, 2)acoustic comfort, 3)thermal comfort, 4)lighting comfort and 5)structure, electric and hydraulic. After the division, it was supplied basic bibliographical material. The activities proposed were:

1- Development of three preliminary studies by the first group.

2- First group make partial presentation of each preliminary study to all groups, in order to debate with them problem envisioned inside each specialty.

3- Each group presents the three preliminary studies, indicating the positive and negative points.

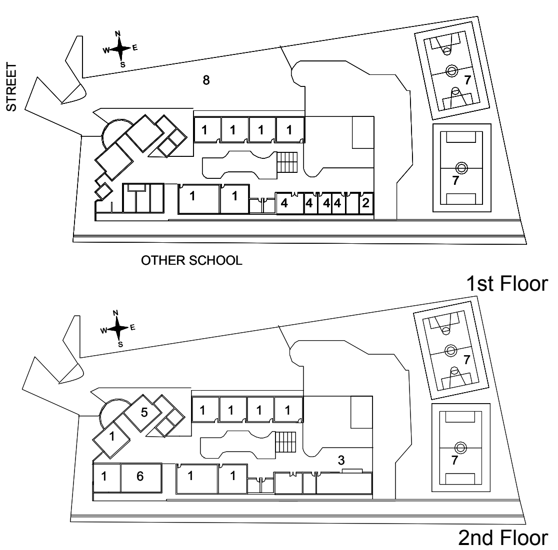
4- After debating pros and cons, students choose a preliminary study for development.

5- Development of design matrix identifying the functional requirements of each group and its parameters of design and formulating the sequence of activities of each group.

6- Presentations are performed by each team with their definitions for the first draft.

For the development of the three preliminary studies, it was chosen the design program and the ground of the school City Soinco 2 in Guarulhos, São Paulo, Brazil. The choice of this school was made because it had passed for an evaluation [4] and belonged to the book edited by FDE [5].

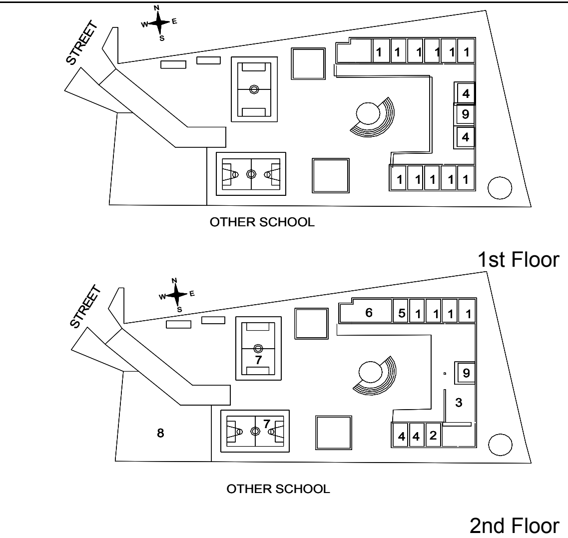
The presentation of the three studies on the part of each of the groups was carried through. Some negative points are shown in the figures 5, 6 and 7.



Legend: 1- classroom, 2- canteen, 3- refectory, 4- bathrooms, 5- video room, 6- library, 7- square, 8- parking

Acoustic comfort	- square in the same level of classrooms - parking in front of classrooms - classrooms in front of neighboring school
Structure, electric and hydraulic	- great openings or free space - structure with forms in curves
Functional comfort	- no access for handicapped people - distant canteen and refectory
Lighting comfort	- classrooms with different solar orientations
Thermal comfort	- some classrooms with south orientation

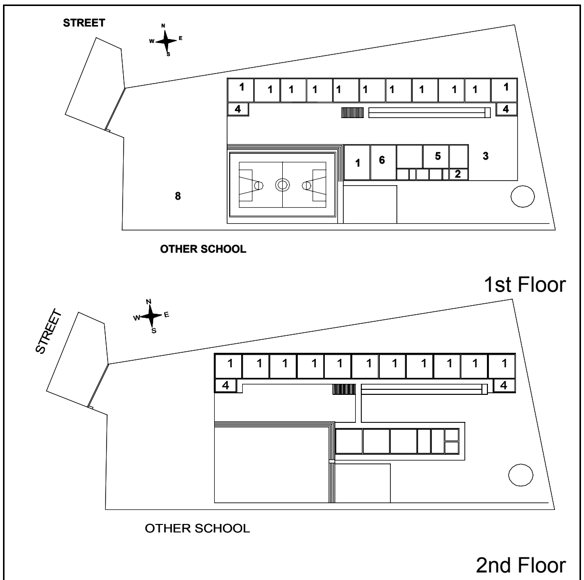
Figure 5: Preliminary Study 1



Legend: 1- classroom, 2- canteen, 3- refectory, 4-bathrooms, 5- video room, 6- library, 7- square, 8- parking 9- elevator

Acoustic comfort	- classrooms with windows next to another school - square in the same level of classrooms - theater centered in the patio
Structure, electric and hydraulic	- elevator use - greater distance for energy distribution and water
Functional comfort	- school not divided into functional block-types - disposal of classrooms harms the layout
Lighting comfort	- bigger area for nocturnal illumination - classrooms with smaller wall for natural illumination
Thermal comfort	- some classrooms with south orientation - bigger exposition of environments to south wind - recreation area without closing

Figure 6: Preliminary study 2



Legend: 1- classroom, 2- canteen, 3- refectory, 4-bathrooms, 5-video room, 6-library, 7-square, 8-parking

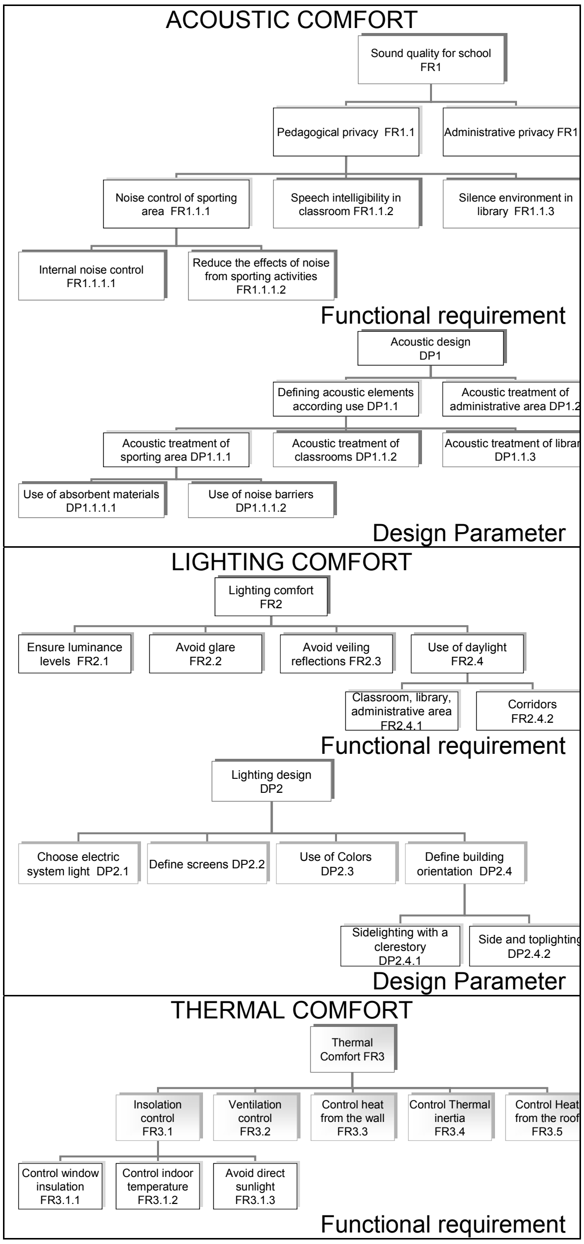
Acoustic comfort	- video room and library are near recreational area

Structure, electric and hydraulic	- bathrooms in the extremities
Functional comfort	- only one square
Lighting comfort	- it did not cite
Thermal comfort	- it did not cite

Figure 7: Preliminary study 3

It was opted to develop the preliminary study 3 because the students considered that the adjustments of this study would be smaller.

For the first draft development, each group made the mapping of functional requirements and design parameters. Figure 8 shows the decomposition into hierarchies of each area.



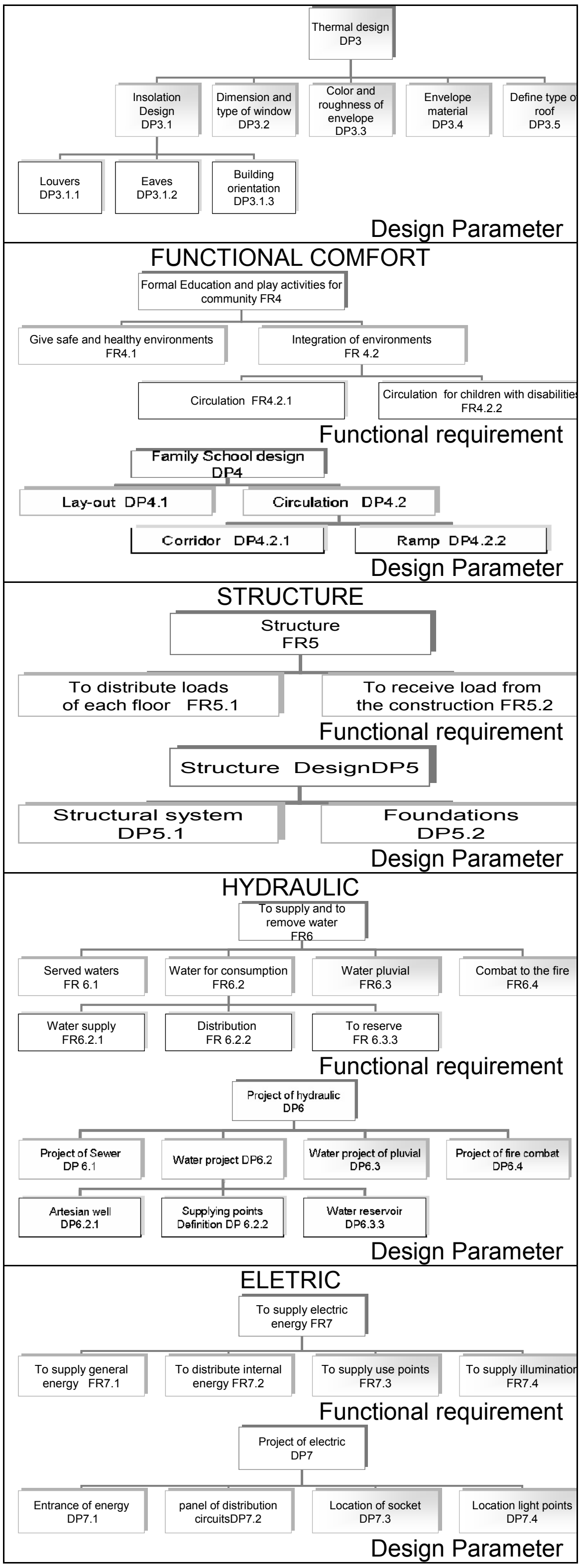


Figure 8: Decomposition into hierarchies

The figure 8 mapping has personal character, that is, it depends on the knowledge of the designer and its experience in the subject. Therefore, the judgment of right or wrong does not fit here. What it is clear is the possibility to register the design process in a rational way.

The decomposition of each functional requirement, shown in the examples of figure 8, in some cases, was simplified by the authors.

Knowing the hierarchic decomposition of all groups, students could understand interferences of each study area. And then they decided the first level order in the design matrix using the independence axiom.

	DP 1	DP 2	DP 3	DP 4	DP 5	DP 6	DP 7	
FR 1	X	0	0	X	0	0	0	FR1 = DP1 + DP4
FR 2	0	X	X	X	0	0	0	FR2 = DP2 + DP3+DP4
FR 3	0	0	X	X	0	0	0	FR3 = DP3 + DP 4
FR 4	0	0	0	X	0	0	0	FR4 = DP4
FR 5	X	0	X	X	X	X	0	FR5 = DP1 + DP3 + DP4 + DP5
FR 6	0	0	0	X	0	X	0	FR6 = DP4 + DP6
FR 7	0	X	0	X	0	X	X	FR7 = DP2 + DP4 + DP6 + DP7

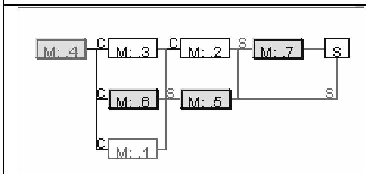


Figure 9: Design matrix and flow diagram of 1st level

It is observed in figure 9 that the design parameter 4 (family school design) influences all the functional requirements, thus it was the first one to be developed. After the definition of the FR4 (formal Education and play activities for the community) was made for the functional group, the group of thermal comfort could develop requirement FR3, the group of acoustic comfort could develop FR1, and the group of structure (electric and hydraulic) could develop FR6 (to provide and to remove water), as shown in the right column of figure 9.

Once the definition of FR3 (thermal comfort), the group of lighting comfort could develop FR2. With the definition of FR3 and FR1 (sound quality for school), the group of structure (electric and hydraulic) could develop the FR5 (structure).

FR7 (to supply electric energy) was developed after the definitions of FR4 (formal Education and play activities for the community), FR6 (to supply and to remove water), and FR2 (lighting comfort).

First hierarchic level indicated the influences or the interferences in the definitions of different study fields for each chosen design function, as well as made possible, through the design matrix, the information flow organization.

In order to develop each functional requirement, each group of students developed design matrices for each hierarchic level, based on the mapping visualized in figure 8.

Figure 10 shows the example of FR1 (sound quality for school) decomposition where it can be seen that:

- In the second hierarchic level pedagogical privacy (FR1.1) and administrative privacy (FR1.2) form a uncouple design matrix and for this reason they can be developed in parallel.
- In the third hierarchic level the design matrix is of the decouple type, that is, there exists a sequence for the development of the functional requirements. First it is developed FR1.1.1 (noise control of sporting area) then it is developed, in parallel, FR1.1.2 (speech intelligibility in classroom) and FR1.1.3 (silence environment in library)
- In the fourth hierarchic level there is a decouple matrix, where FR1.1.1.2 is defined first (reduce the effect of noise from sporting area) and later FR1.1.1.1 (internal noise control).
- The flow diagram indicates these information

ACOUSTIC COMFORT

2° hierarchic level matrix

	DP1.1	DP1.2	
FR1.1	X	0	FR1.1 = DP1.1
FR1.2	0	X	FR1.2 = DP1.2

3° hierarchic level matrix

	DP1.1.1	DP1.1.2	DP1.1.3	
FR1.1.1	X	0	0	FR1.1.1 = DP1.1.1
FR1.1.2	X	X	0	FR1.1.2 = DP1.1.1 + DP1.1.2
FR1.1.3	X	0	X	FR1.1.3 = DP1.1.1 + DP1.1.3

4° hierarchic level matrix

	DP1.1.1.1	DP1.1.1.2	
FR1.1.1.1	X	X	FR1.1.1.1 = DP1.1.1.1 + DP 1.1.1.2
FR1.1.12	0	X	FR1.2 = DP1.1.1.2

Flow diagram

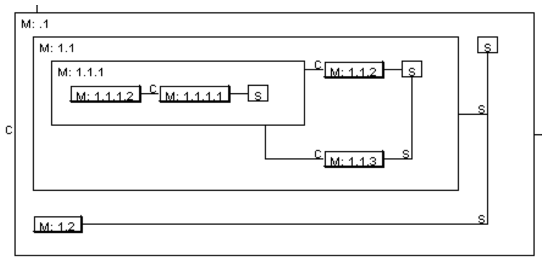


Figure 10: Examples of flow diagrams and matrix of inferior hierarchic design levels of acoustic comfort design

Flow diagram of the whole design was elaborated. One can observe in figure 11, definition and information sequences, as well as interferences of each field of study.

With the development of this process, and following definitions of the design matrix and flow diagrams (figure 9 and 11), it was possible to organize a chronogram of the activities of each group for the remaining semester.

Fifteen days after the act of receiving the information to develop module 7 (last one), projects oral presentations with definitions of each team were scheduled.

Presentations were carried through seminars, and each team made a descriptive memorial with all definitions.

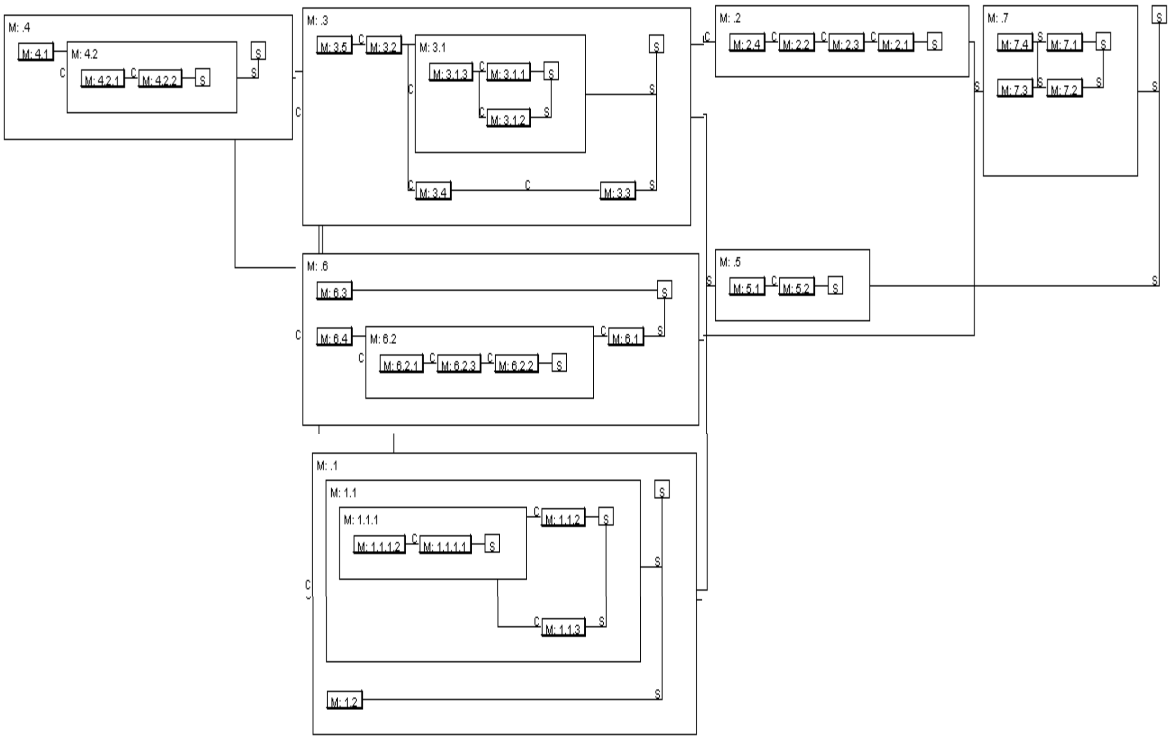


Figure 11: Flow Diagram of all the hierarchic levels

5. CONCLUSION

Initially, it was observed that the students had a certain resistance to plan and to decompose the design in accordance with the proposed methodology. It was observed two distinct types of behavior: the immediate solution of the problem in simplistic way without consideration of other possible solutions, or generic definition of the problem without necessary detailing.

The axiomatic design method allowed the recognition, by the students, of interferences of different fields of study. When perceiving these interferences, the use of the axioms allowed managing information and design decisions in order to decide a sequence for solving the problem, which facilitated the design development.

The use of environmental comfort as a paradigm for the design development, in all design process, made possible understanding its influences in each project decision. It can be said that the students had taken conscience of the importance of each comfort, and that probably had become aware of its necessity. This was only possible by fact of dividing the classroom into five groups, and each one defended its area of study in the development of an only project.

REFERENCES

[1] Suh, N.P. The principles of design. New York: Oxford University Press, 1990
[2] Lindholm, Tate and V. Harutunian. Consequences of design decisions in axiomatic design. Journal of integrated design and process science. (1999) v. 3, n° 4,
[3] Suh,N.P. Axiomatic Design theory for systems. Research in engineering design.(1998)10:189-209
[4] V.A.Graça. Otimização de projetos arquitetônicos considerando parâmetros de conforto ambiental: O Caso da rede Estadual de São Paulo. DISSERTAÇÃO (mestrado), Universidade Estadual de Campinas, Faculdade de Engenharia de Construção Civil, Campinas, São Paulo, 2002
[5] FUNDAÇÃO PARA O DESENVOLVIMENTO DA EDUCAÇÃO (FDE). Arquitetura escolar e política educacional: os programas na atual administração do Estado. São Paulo, 1998.