COMPUTER-AIDED PLANNING OF CONNECTIONS AMONG BUILDING COMPONENTS

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Abstract

In these last years the use of advanced technological types of construction, prevalently consisting of mechanical assembly systems, is also spreading to create connections among building elements.

The aim of the research we are carrying on is to develop an automated software tool aiding the planning of assembly systems adopted in building, which are often characterised by high complexity levels.

At the present, such subject is being studying in the mechanical field; but the difference of components and of products, seldom mass-produced and industrialised in building, make only few factors be available to our field, where further and different investigations are required

The paper will show the progresses of the research proceeding, al the moment, along two directions:

1) The assembly simulation through:

- automated analysis, through the use of a mathematical model, of the formal and functional compatibility among the connection components,

- automated representation of the sequences of installation phases of each component on different planes of the space;

- generation of exploded isometric drawings of the separate phases and of whole the complex; - sequence movements of components.

2) Identification of the factors which cause the assembly optimization (type and position of components, assembly sequences, etc.) and determine the reliability during the use.

We think such a tool, by providing some more punctual information about assembly sequences and procedure, should be useful with regard to education and practice, both to conceive the building connections and to analyse installation times and modalities.

1 Introduction: Utility and Finality of the Study

Observing, nowadays, parts of some buildings it is common to come across pieces, such as bolts, metal profiles and connectors, at one time unthinkable in the execution of architectural structures. In fact, only for some decades there has been an increasing propagation of assembly systems that adopt pieces and modalities for the set up analogous to those adopted in the mechanical engineering field.

The manifestation of this tendency is attributable to a series of concomitant factors which are: - the necessity to make use of industrial products;

- the propagation of some types of dry connections;

-the standardisation of the products and processes.,

-the advent of innovative materials;

- the increase use of technology as an expressive means ("High Tech').

Some of the above mentioned factors contribute to the reduction in time and cost, obtaining higher levels of functionality, precision and required reliability during the exercise and execution phases of modern buildings. In this sector, during the course of experiences matured in the last decades, it was possible to verify how the most immediate advantages, deriving

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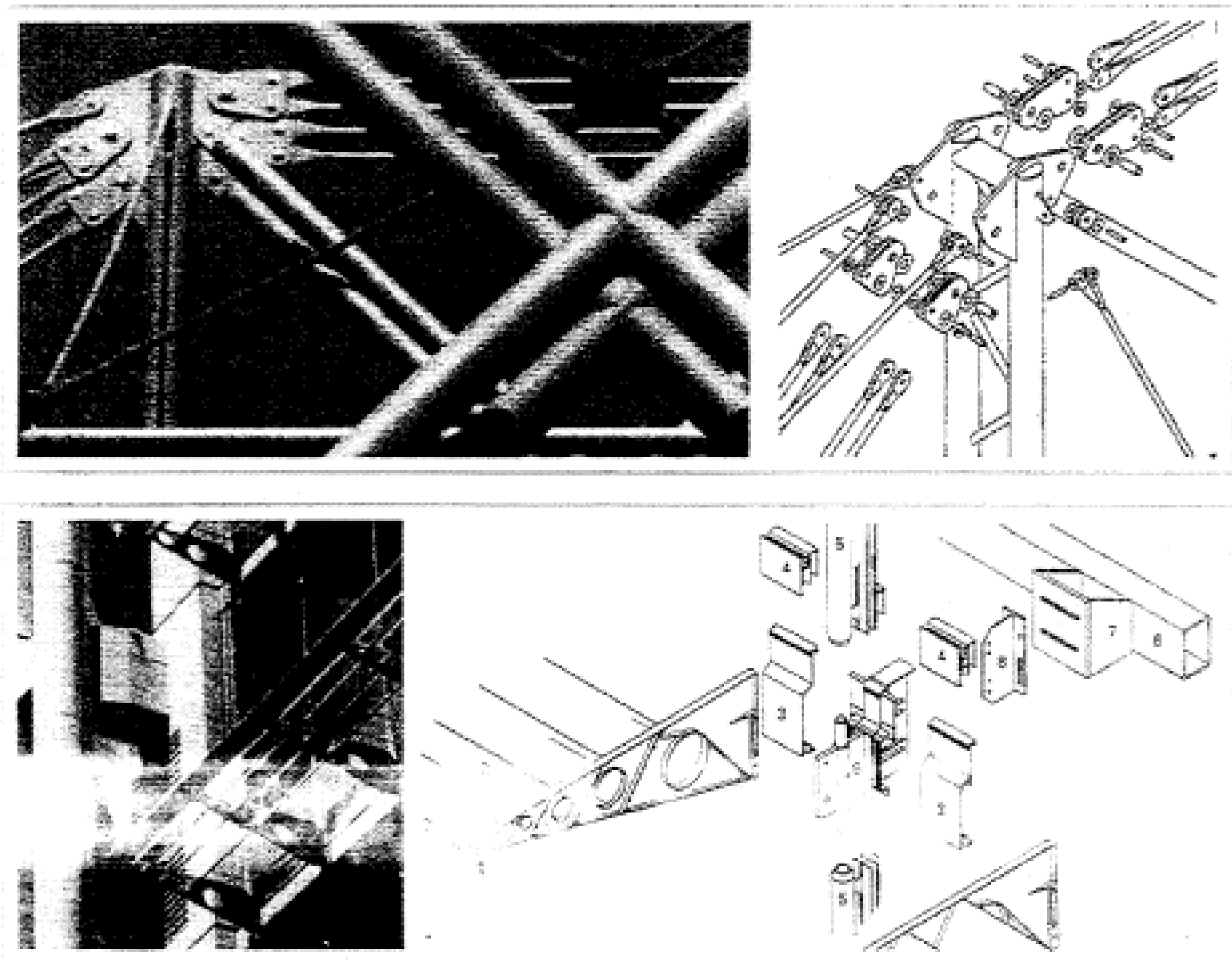
from the traditional mechanical type systems, reached the possibility to solve technical problems and achieve ever more complex and original solutions having to do with shape; these were favoured, moreover, by new variations which granted the same pieces and procedures an elevated originality in the disparate situations that incur in the building sector.
However, on one hand, these systems, by their own versatility, permit elevated quality levels of the realised building elements ; on the other, by the same versatility, guaranteed by the variety of possible geometrical and technological features for the components and for the entire assembly and by the different relating execution procedures, they involve a remarkable complexity in their conceptual idea and in their planning control.
This complexity can already be observed in the representation of constructional nodes that are constituent parts of existing buildings: the process that led to their execution (assembling) is frequently of difficult interpretation.

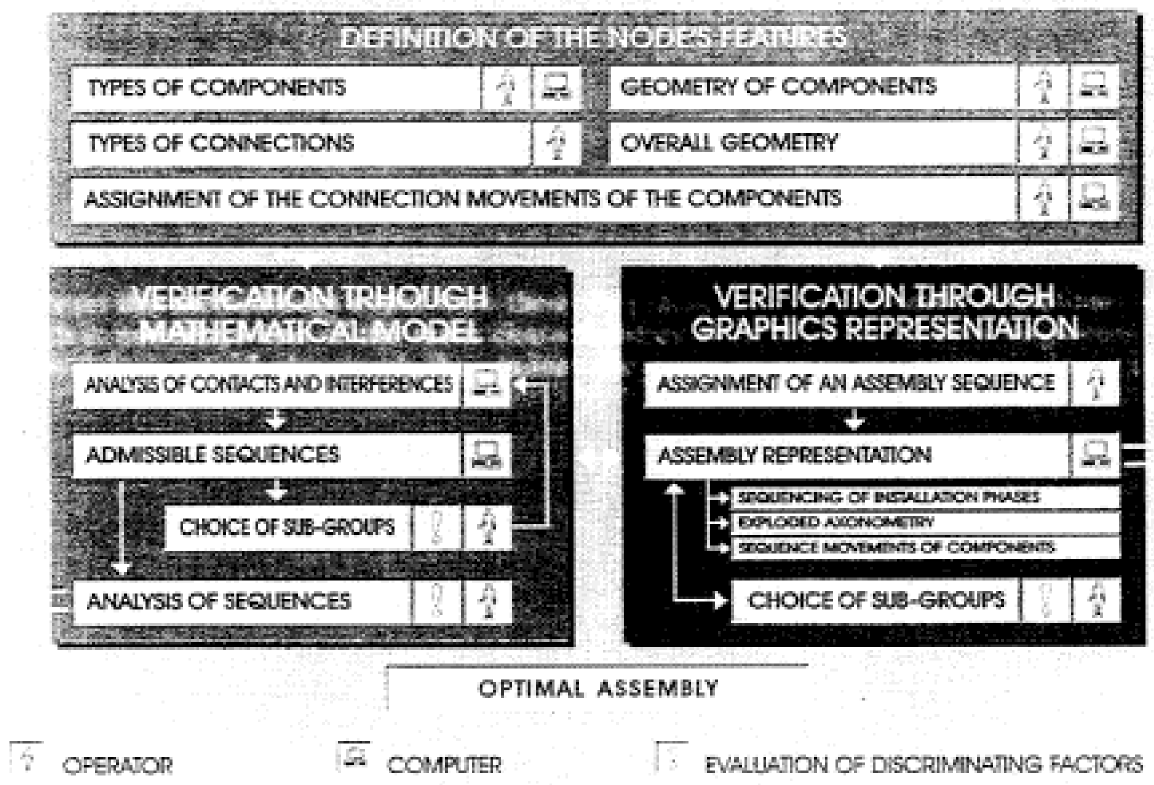


The complexity of the two nodes, made up of an elevated number of components requires a planning work not comparable to the one necessary for commoner systems. The aim of the assembly representation is to check on the planning choices even before finishing information on executive modalities. What mentioned before is especially true in the second node in which there are elements present that, performing different functions, require verifications on planning problems of other orders. R Roges, Fabbrica IMNOS a Newport. Takenfrom: C Aymerich, Architettura e Tecnologia, Cagliari 1992. Foster Associates, Banca di Hongkong e Shanghai a Hongkong. Taken from: A.J. Brookes e Chris Grech, Hi-Tech, Milano 1992.

Even more complex, therefore, is the same conceptual idea of similar nodes: in many cases, it is even necessary to make use of solid scale models, constantly modified to improve the same assembly or final functioning.
In the planning phase, the aid of automated software of assembly simulation is believed to be useful. Such tools, presently in use for the definition of mechanical assembly, show a limited adaptability in specific problems of the building sector, characterised by the modest mass production of products and by the poor industrialisation of the assembly procedures on the work site. When intending to adapt these tools into the building sector it is, therefore, necessary to take into consideration those discriminating factors peculiar to the assembling of constructional nodes. These factors, once coded, will contribute to directing and evaluating the results of an automated analysis; this analysis can be based on a mathematical model similar to the one put to use for the mechanical case or can be combined with graphics representations of the node which, when simulating assembly, permit a more immediate conceptual idea of the assembly.
We believe, the co-ordinating application of both graphical and mathematical methods would allow for an easier way to define the appropriate geometrical features and the optimal sequence for the assembly of constructional nodes in the building sector that present a remarkable complexity.

2 Tool Description

For aid during planning of complex assemblies the object is to develop an automated tool involving an operative method made up of different, articulate and interactive phases summarised in the following ideogram.



The ideogram shows how one could achieve the individuation of an "optimal assembly" intended as a group of components which can be connected together by the "shape compatibility" of the parts and by "taking into account particular executive needs".

- The shape compatibility is the requirement for the components that, through positional geometrical features and through connection modality ones, do not cause interference[1] during the assembly phase;
- The observance of particular executive needs is evaluated through -discriminating factors"[2] that contribute, having been internally evaluated in some of the phases, to the achievement of the optimal assembly.

The operations taking place inside the different process phases can request direct choices made by the operator (symbol of man in the ideogram) or make use of the automatic intervention by the computer (computer symbol). Furthermore, in some phases, it is indispensable to evaluate the discriminating factors mentioned (hand symbol) in order to contribute in the operation of the choices which allow or render an even more immediate passage to further phases.

3. Definition of the Node's Features

The first phase of the design of a constructional node generally consists in the empirical operation for choosing its technological features (geometrical and functional) taking advantage from well known models where the main performances, furnished inside specific structural parts of the building, are known. These features regard the single components, the relationships between these components and the node in its entirety.

This phase is a preliminary moment of the design and involves numerous and complex evaluations of opportunity on the part of the operator. The computer, through a CAD software, not only allows for an initial graphics representation but can supply a directory of useful examples regarding the types of components, corrections and analogous nodes.

3.1 Types of Components

The choice of components can be carried out by making use of the aid furnished by a library containing a large range of existing pieces on sale having geometrical features and known physical features.

On the contrary, some assembly requires special components according to their form and function, which will be realised on command, therefore, not found in any library, but can be introduced in order to use at a later date.

3.2 Types of Connections

What we mean as "types of connection- between two components of the node, each one consisting of one or more elements formerly made integral, is the type of coupling relationship that can exist between the elements in order to assemble them.

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[1] *An interference along a generical direction is manifested when, during the movement in the assembling and disassembling phase, an element collides with another already assembled one.*

[2] *The discriminating.factors indicate essential criteria of choice in the designing of a node and refer to specific aspects of execution.*

Factors regarding the form, dimension, weight, the tools usedfir installation and the modalities of movement, indeed, have an influence on: choosing the type of connections, the arrangement and modality of assembling a component to others, individuating subgroups and sequence analysis.

The choice of connection types (screw, welding, fixed joint, etc.) is carried out by the operator on the basis of working criteria during the exercise and execution phase, and considering, during the assembly operations, the convenience and saving of time.

3.3 Geometry of Components

The geometry of the components is determined by the relating form and dimensions. These are usually defined on the basis of the type of their material, static scaling criteria and on the particular function inside the node and inside the structure part which the latter contributes to constructing. The geometry of the component can be pre-defined in the case of a standard component taken from the library, and can be defined by the operator, if the piece is a new concept.

3.4 Overall Geometry

Overall geometry depends on geometry of single components and on their absolute and reciprocal position.
The objective to obtain a precise geometry of the entire node can influence the choice on its components (types and geometry of the components). In the definition of overall geometry the operator can also take advantage of a library of examples from which he/she can get ideas for the definition of analogous nodes.

3.5 Assignment of the Connection Movements of the Components

The movements necessary for each component to be connected to other pieces (shifting movements, rotating movements, rotoshifting movements) are attributed.
The operation can be automated if the component is chosen from the library; in that case, the shifting or rotating directions are, in fact, directly associated by the software on the basis of the geometrical features of the component.

4. Verification through the Mathematical Model

The automated verification makes use of a mathematical model easily run by software which represent the product in order to generate the disassembling cycles (or assembling ones, when considering the contrary); the model is founded on the matrix calculation and on the theory of closed routes of graphs of relationships deducible by the same matrixes.[3]

4.1 Analysis of Contacts and Interferences

The geometrical features of the node are extracted from the CAD model.
In order to make this happen the assumption is the possibility to create an adequate interfacing between the CAD system and the adopted automated simulation software.

[3] *This mathematical model is in the developing phase at the present in the mechanical engineering field. 1t is part of a software system (FLAPS, Flexible Assembly Planning System) for automated programming of machine assembly lines which involves the automated preventive planning of assembly operations.*
Cfr. M. Santochi e G. Dini, "Automated Sequencing and Subassembly Detection in Assembly Planning", in *CIRP ANNALS 1992 Manufacturing Technology, Vol.41/1/92.*

The relationships of reciprocal position of pieces, already connected or during the relating movement phase (contacts and interference), are translated into matrixes through the simulation, within a CAD, of the shifting of components (single piece or subgroups) along the three main directions or the other directions indicated by the operator. In this way three contact matrixes, three interference ones and three connection ones (one for each principal direction) are created. All of the matrixes are extracted automatically assigning codes to the data relating to the types of movements and connections introduced in the first phase. These numerical codes should consent to individuate the elements connected by those in simple contact.

4.2 Generation of all the Admissible Sequences through Compatibility Verification

The analysis of the contacts and interferences takes place through the updating of the matrixes step by step each piece shifts as soon as disconnected from the node. The analysis supplies the disassembly order of the components in the directions studied if no closed graphs with oriented routes associated with the interference matrix are revealed.

This is how the admissible sequences are generated (the sequences also can be in considerable numbers, being in "n!" numbers if "n" is the number of components).

The condition of admissibility consists in the power to match all the components along such directions so as not to interfere with other components already positioned.

In order to reduce the number of sequences, the operator can formerly establish to the assembly order of one or more components relating to others.

4.3 Choice of Assembly Subgroups

A subgroup is a partial set of components connected among themselves apart from the total assembling phases of the node.

A subgroup is, therefore, a unique component, made up of few simply assembled elements, or a prefabricated component, also made up of an elevated number of pieces.

Subgroup individuation is carried out according to simple models well known by the operator and also taking into account the discriminating factors regarding particular assembly needs.

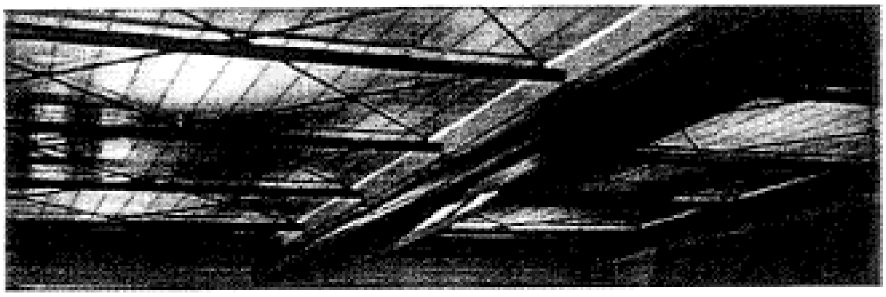
The evaluation of the subgroups allows for a quicker verification; in fact, since reducing the total number of node components, it diminishes the number of admissible sequences and the operations of analysis of contacts and interferences. To achieve this aim it is necessary to iterate the latter operation in order to verify how the subgroups, which have now become unique components, are compatible with other node components.

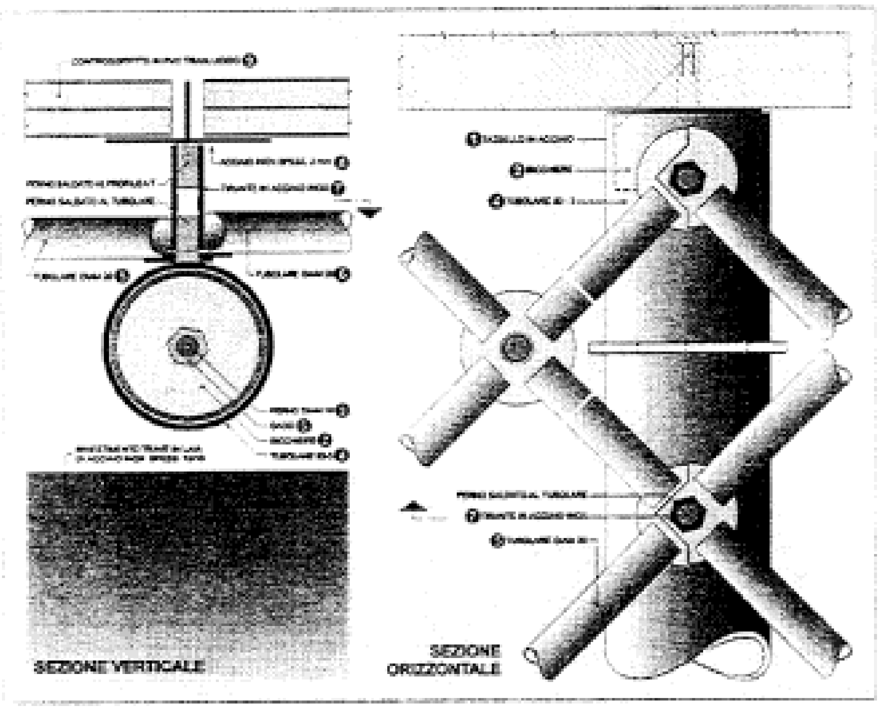
The admissible sequences can be in such numbers to be analysed and evaluated one by one or so many as to request further or different subgroups.

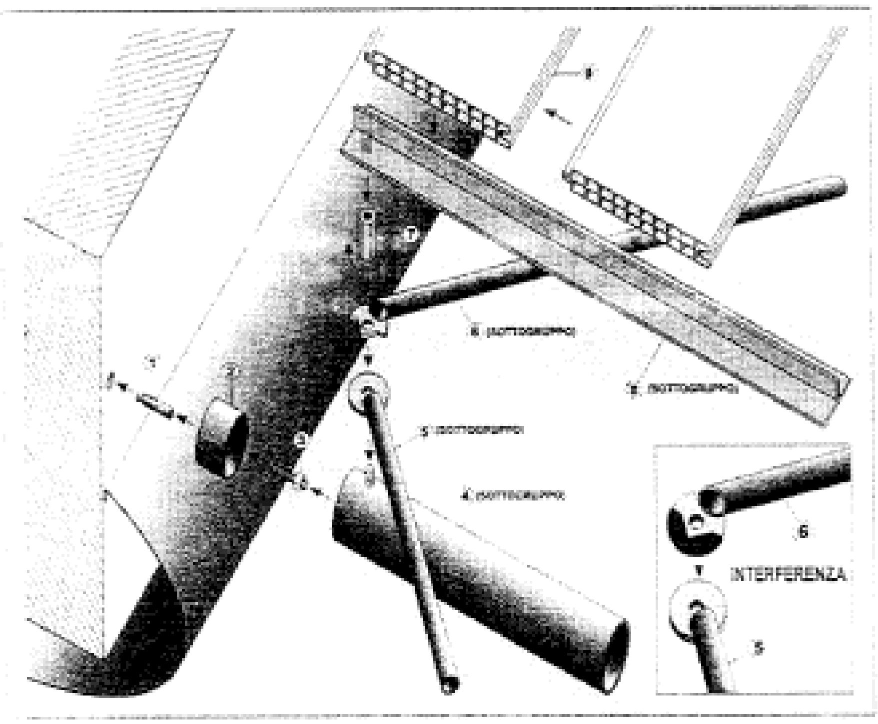
4.4 Analysis of the sequences

Once the admissible assembling sequences are automatically obtained, it Is necessary to choose the ones that are most suitable to the needs of assembly execution, by evaluating the "discriminating factors". It is possible that among the generated sequences none respects these needs; in this case it is necessary to redefine the node's features.

Therefore, an iterative process is generated; for further approximations, it leads to the reduction of the sequences and to an ever more appropriate assembly individuation, reaching, at the end, the optimal one.







Ceiling of the conference hall of the Facoltà di Ingegneria di Palermo. A. De Vecehi, Dipartimento di Progetto e Costruzione Edilizia, Palermo 1992. The adopted constructional system presents some relatively simple nodes; nevertheless they involve problems with assembling not immediately foreseeable in planning phase.

The detail of the overlapping of the two braces (5 and 6) welded at the respective circular plates is emblematic. It shows how an "interference", without opportune outlining of the upper plate, would take place. The coupling of some of *the components in the four subgroups was made necessary to avoid an imprecise and difficult connection through welding, if carried out during the disassembling phase. This is also due to the dimensions and the shape of the pieces (discriminating factors). Furthermore, the individuation* of *the subgroups reduced the number* of *assembly phases from 13 to 9.*

This device would determine a minor number of admissible sequences if the mathematical model were used for the verification of assembly compatibility.

5. Verification through the Graphics Representation of Assembly

Graphics verification consists in automatically creating a series of images that consent to verifying the compatibility of assembly through simulation of the phases for setting up each component. We believe types of such simulations can furnish a very close representation to real executive problems. Thus allowing for a higher control of node compatibility in the assembly phase.
We are studying the possibility of developing a software, running within CAD, which, starting from the *definition of the node's features* phase, consents to automatically obtaining three types of assembly representation illustrated further on.
This method can make use of the aid of the method based on the mathematical model that, for example, can carry out a role selecting rapidly admissible sequences and excluding, by an initial verification, the assembling in which interferences are generated.

5.1 Assignment of an Assembling Sequence of the Components

To each component a number that represents the order with which it is connected in sequence during the assembly is assigned. We will return to modify the sequence if, from the analysis of further phases, the conditions are not satisfying enough to consider the assembly optimal.

5.2 Assembly Representation

5.2.1 *Sequencing of Installation Phases*

The sequencing of the phases consists in bi-dimensional instant images of the components, on three Cartesian levels and three-dimensional axonometric ones, according to the assembling sequence formerly assigned.
The contemporary view of the assembly phases in the hypothesised sequence can favour the verification of effective feasibility.

5.2.2 *Exploded Axonometry*

The exploded axonometry highlights the position of each component disassembled by the node, indicating the necessary movements for connection. Furthermore, the contemporary view of all the components of the node from all the possible points of view permits evaluating the reciprocal position and the interconnection relationships.

5.2.3 *Sequence Movement of Components*

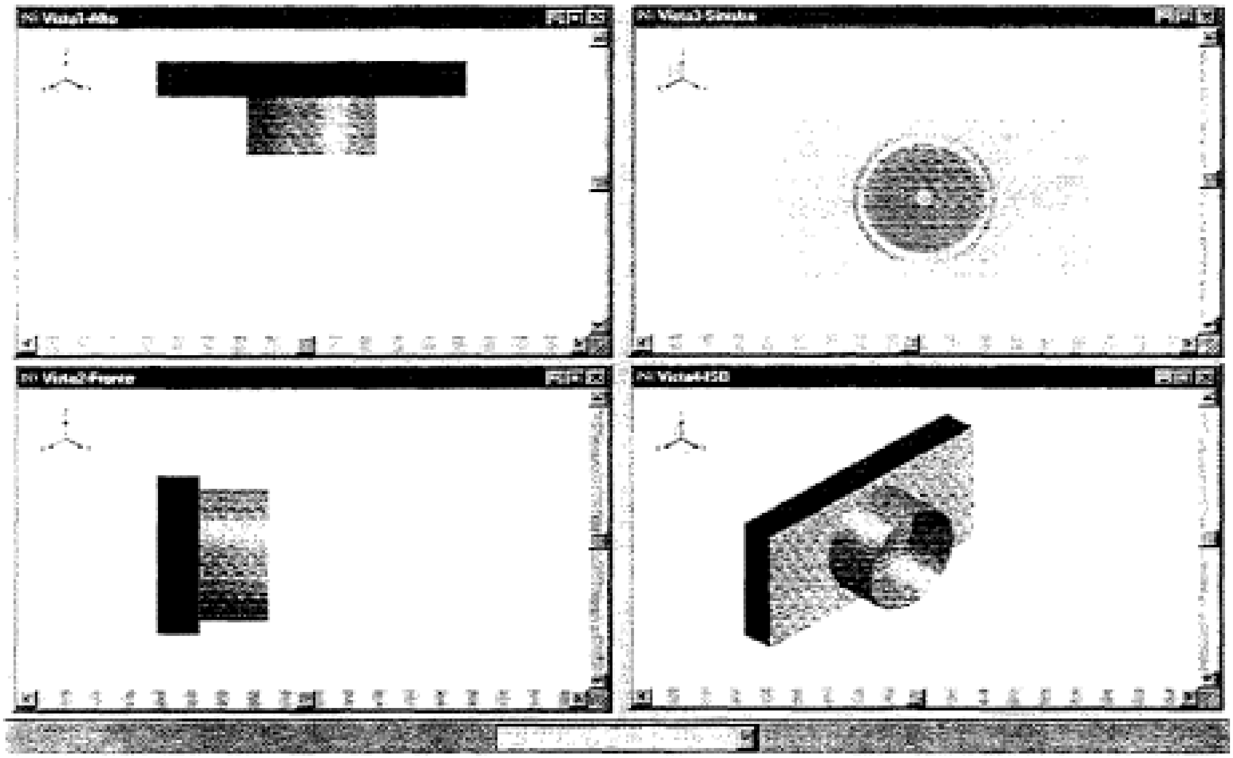
According to the order of assigned assembly the single components appear on the screen and are positioned in the node after putting into effect a route based on pre-established movement (direction and rotation). This can be obtained in bi-dimensional representation, in the three levels, and in three-dimensional representation.

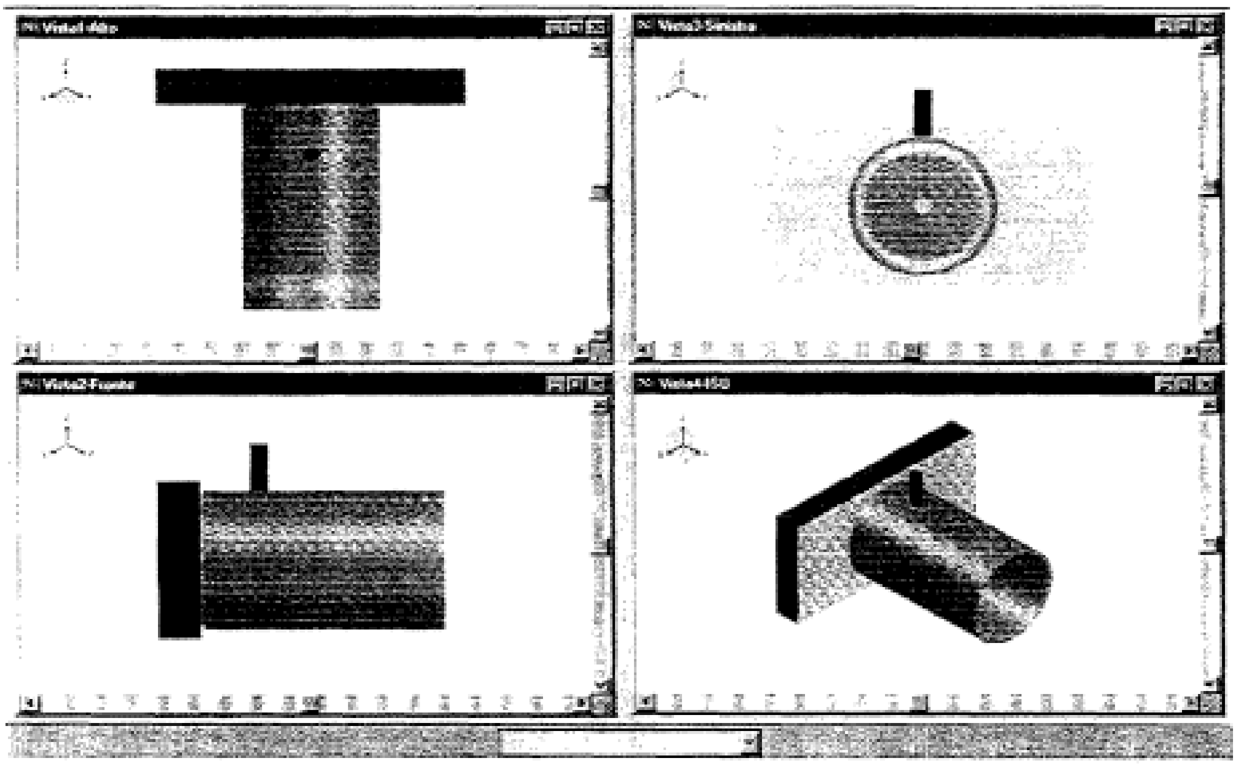
5.3 Choice of Assembly subgroups

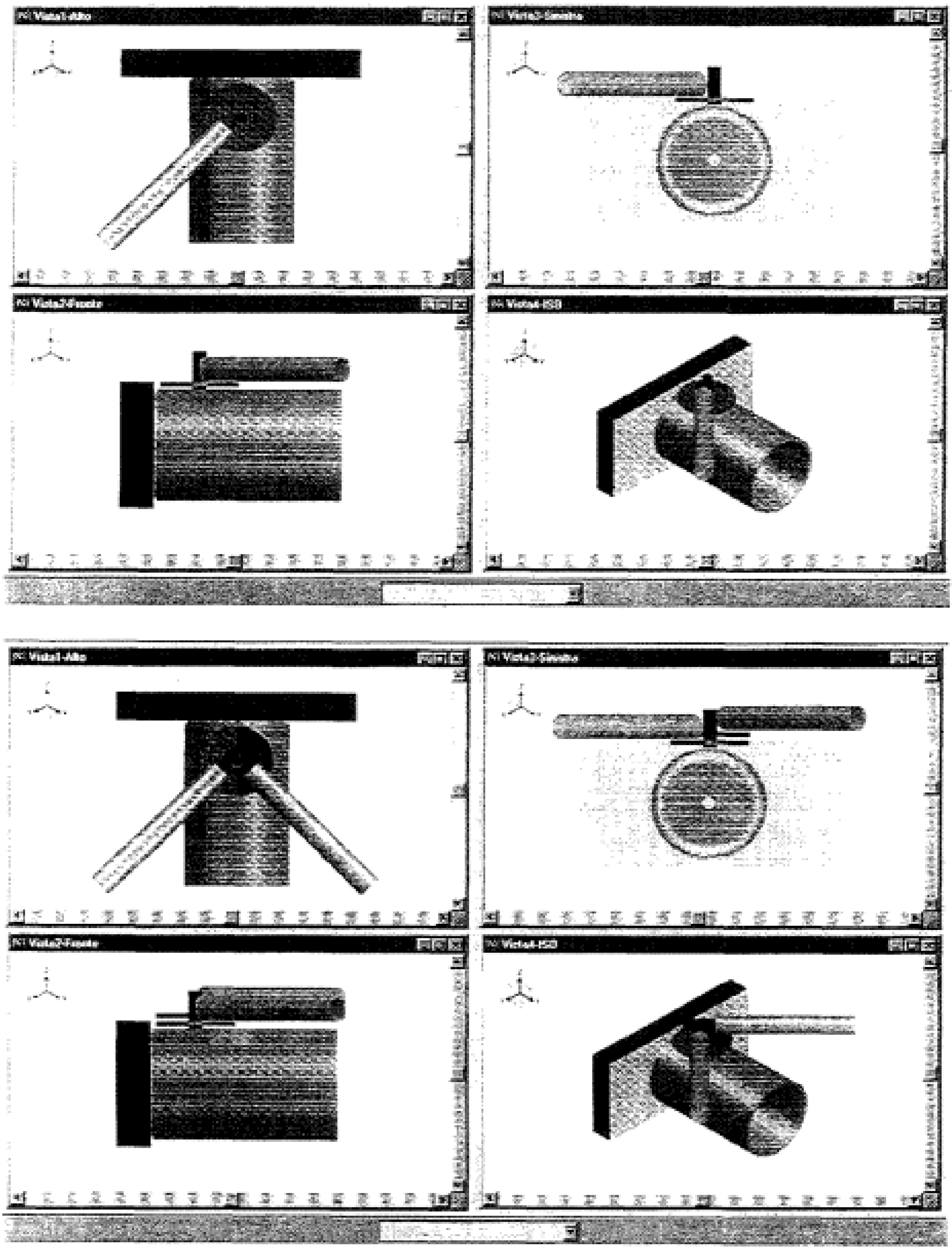
The choice of subgroups, with the same valence mentioned previously, is facilitated here by the visualisation of the geometrical features of the components and of the node in general. For this reason and for the higher aid to representation of executing problems, this part of the tool can integrate the analogous moment into the verification through the mathematical model.
Thanks to the automation all of the representations described up to now can be step by step updated each time some modifications to the node are made.

6 CONCLUSIONS

What mentioned above describes the general scheme of our study; at the present, we are simultaneously studying the different parts of it. In particular the following illustrations exemplify one of the phases belonging to the *verification through assembly graphics representation.*







Four sequence phases of the assembling of the node previously represented are reported which illustrate one of the three ways of assembly verification through graphics representation. XCAD (shading) drawings belonging to a thesis which is being carrying on by C. Di Miceli.