SYSTEMATIC DESIGN ANALYSIS FOR (ROD) DESIGN SYNTHESIS SHOWN AT THE EXAMPLE OF A STRUCTURAL JOINING SYSTEM SUITED FOR ROBOTIC ASSEMBLY

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ABSTRACT

Based on the concept of "Robot Oriented Design" which was presented at the 5th international symposium on robotics in construction in June 1988, this paper proposes a design analysis for the "ROD" robot-oriented-design synthesis of structural elements. The structural elements are beam and column including their joining system. A systematic method for analysing the design of a structural joining system is proposed. This should result in the establishment of design catalogs whose content could be used for alterations or redesign and new design synthesis of structural joining systems suited for robotic assembly.

Design Methodology

Robot oriented design stands for a systematic design method during the design process. According to Hansen (1)the constructional science is a discipline of technical sciences which analyses the development process in order to discover rules or guidelines for the design activity which result in rationalizing these processes.

The constructional science aims at establishing a knowledge base for the design process and to show the way of designing solutions. As far as design in architecture is concerned the constructional science deals mainly with the constructional process of development as a partial process of the total development process of architectural design, which is understood as the technical design of buildings. Another emphasis is put on the description of building specifications in such a way that these informations can be used for the design process at various stages. This means that the required design information is stored at different levels of abstractness in catalog form in order to be easily accessible during the design stages.

Theme of Study

Since the research in construction robotics and related fields is very recent it was decided to analyse existing joining systems in construction in order to discover the

construction process. By this means some data bases can be set up and the methodical procedures during design process could be simulated. In the future the functionability of these data bases and the procedures should be tested by an example in order to check its liability.

Localization of Theme

A building can be considered as a technical structure. This technical structure can be subdivided in different subsystems such as: Structural system- Exterior system- Interior system.

Installation system

Each of these subsystems consists of several building parts and groups which are more or less complex. This study focuses on the structural subsystem in general and the joining system between column and beam. There can be between 1 and 4 horizontal elements and 1 vertical element in relation to each other. According to the various influences acting on the joining system the total function and the subfunctions are decided:

The influences acting on the structural joining system are caused:
-by external loadings such as live loads, wind loads etc
-by permanent loadings such as dead weight
-by deformations such as temperature changes,live loads etc.

These loading influences decide the subfunctions such as:
-force transmission within the joining elements
-moment transmission within the joining elements
-force tansfer between structural elements and joining elements
-moment transfer between structural elements and joining elements

Furthermore any joining system has to comply with the function of assembling which consists of the following subfunctions:
-Positionining of building elements
-Adjusting of building elements
-Fixing of building elements.

Additional constraints for the structural joining system are:
-type and elementation of structural system
-type and elementation of exterior-, interior- and installation system
-physical constraints such as corrosion
-geometrical conditions during assembly process
-material oriented constraint

-production oriented constraints
-economical constraints
-etc.(2)

From these various influences and constraints result further subfunctions. For the purpose of promoting the design for robotic assembly in construction the author focussed on the assembly-subfunction and its resulting subsubfunctions.

Analysis

The analysis consisted of the following steps:
-data collection of joining systems between column and beam
-documentation of joining systems and categorized
-analysis of joining surfaces, joining motions in order to understand the subfunctions of positioning, adjusting and fixing
-definition of graphical symbols
-set up catalogs consisting of analysis datas for future design of joining systems for robotic assembly (In the future)

Outline of Systematic Design Process

A design strategy for methodological design is to subdivide the design process in subprocesses, which will be dealt with sequentially including feedback processes. The 4 major design stages are:
-planning -concepting -designing -detailling

Planning Stage

During this stage the marketability is checked, trends are analysed, research results are collected, consumer needs etc. In case of satisfying outcome the go ahead for further development is decided.

Concepting Stage

This stage starts with clearing the problem definition. The results gained from hereby are listed as requirements. This requirement listing should consist of data about the minimum and maximum requirements concerning the total function and the subfunctions including costs and deadlines. These requirements are used in later stages for the evaluation of the total-and/or sub-solutions.

Design Stage

This stage is based on the selected conceptual solution from the previous stage. The solution is drawn in scale. Weak points are corrected till an optimal design is choosen.

Detail Stage

During this stage single parts are designed and optimized and the engineering data are set up.

In this paper only the concept stage is considered, since this is the stage of design where most of the cost of a product are decided. The concepting of a technical product occurs in two phases:
-the function finding phase, in which the total function and subfunctions are elaborated
-the geometrical-physical phase, in which solutions are related to the various subfunctions.
With these two phases the function and structure of a technical product can be described .

Definition of Assembly Operations

Each assembly operation consists of several subassembly operations. The assembly operations can be executed at the factory and/ or the building site. Operation of assembly work consist of:
-positioning -adjusting during assembly work operation
-fixing

Before these subassembly operations are defined the notion of adjusting is described:
Adjusting requires skill which can hardly be executed by common robots except for most advanced robotics. Adjusting means that building elements have to be moved during or after assembly work operation in such a way that they can be positioned in the required location of the technical structure. This results in geometrical and mechanical operations.

It is obvious that the notion of accuracy becomes very important during robotic assembly operations in order to relate the necessary adjusting motions to one of the remaining 3 types of movements as above mentioned.

Accuracy

Accuracy during production means that an element can move within its limits of accuracy while complying to its function. During assembly however the allowable location ranges are greater than the accuracy range. This type of accuracy is considered since it is suitable for robotic assembly.

Suboperations of Assembly Work Operation
Positioning

The effective areas of two elements approach each other and

the final position before adjusting operation is controlled. If required other joining parts as screws or bolts are also positioned. In this study it is assumed that only one positioning operation is required before adjusting or fixing operation.

Adjusting

The effective areas of two elements are further approached to each other before fixing operation in such a way that the function will be fulfilled. Joining systems consisting of long holes are considered as a shiftable adjustment and other joining systems are considered as definite adjustments.

Fixing

The effective areas of the elements are moved to aech other in order to secure them against any further change of position. In the following analysis it is assumed that the column is already positioned and fixed before the beam is positioned and fixed. Furthermore there is the possibility that some suboperations might be executed simultaneously during the assembly work operation.

Classification of joining systems according to functional criteria

Joints consist of several elements or at least two joining elements and no,one or more coupling elements. These elements relate to each other in a functional,geometrical and physical way. In the relative position the joining elements relate to each other in the way which is shown in step 3. During positioning the relative movement between two elements is shown, which is required for the assembly work operation during the positioning stage. During adjusting the movements are shown that are possible during adjusting within the allowable limits and accuracies.

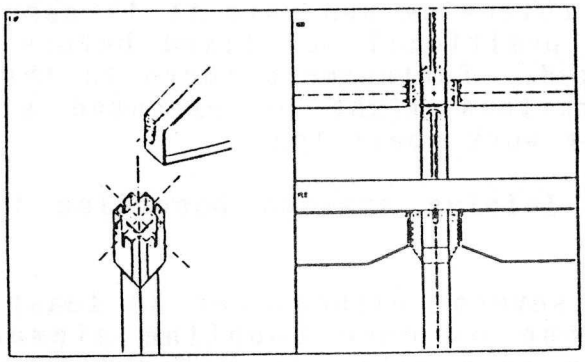
Aim of Analysis

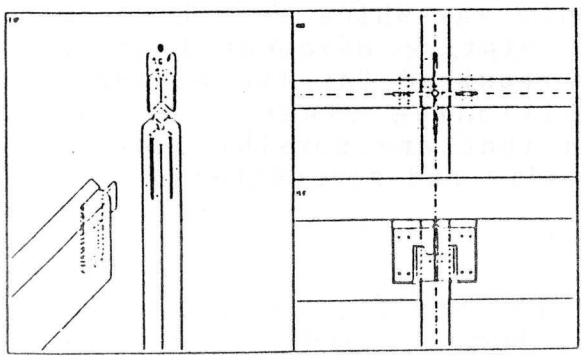
It is intended to set up a knowledge base for the design or redesign of structural joining systems in order to enable future assembly by robots. Therefore the knowledge base should contain the structural properties of basic elements of joining systems which are categorized according to functional criteria. The analysis aims at splitting up a complex structure into some less complex structures. The analysis is therefore the reversed design process where the input into analysis is equivalent to the output of design process and vice versa.

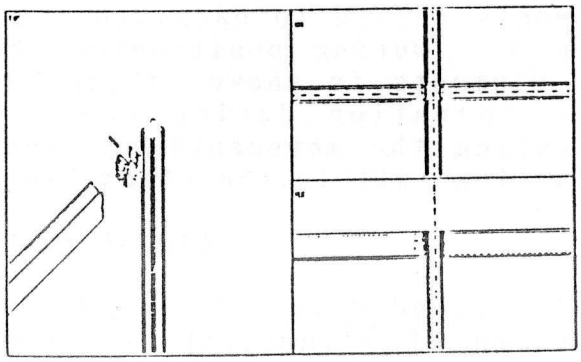
The phase of concepting consists of a functional and geometrical-physical phase. Therefore an existing structural joining detail has to be analysed for its function related elements and structural properties. This has to be described at various levels, i.e. the abstract and the concrete level.

The Process of Analysis
1st Step

Documentation of the concrete building structure of the joining system:
- horizontal section - vertical section - explosive drawing
- short description of structural system
- short description of assembly process
- functional description concerning transmission and transferring of forces and moments
- indication of further possible positions and orientations of joining building group.

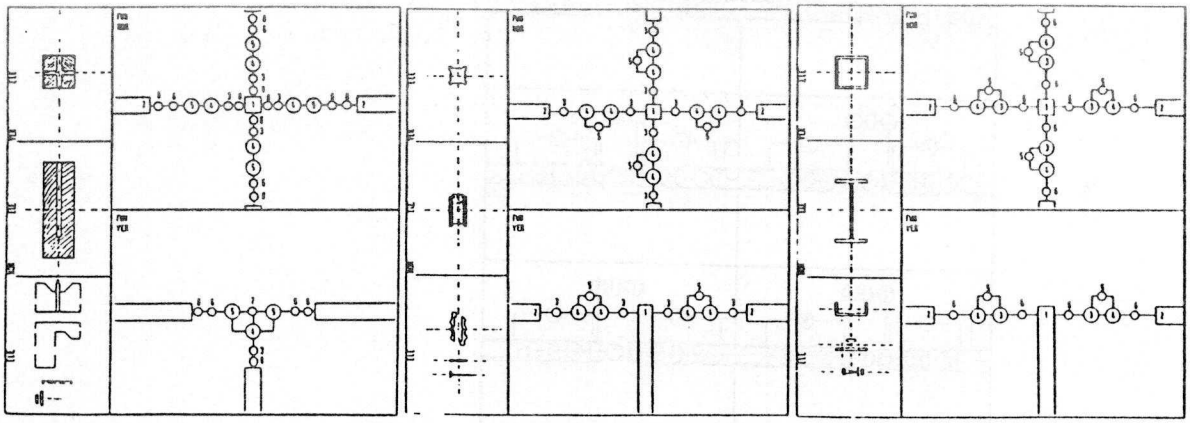






2nd Step

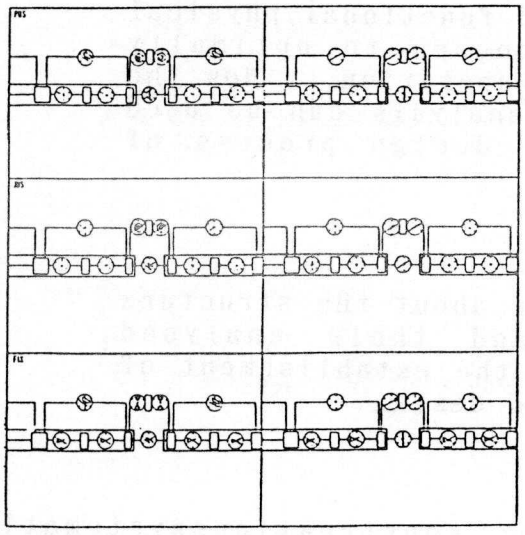
Classification of the joining building group according to its functional properties:
- orientation of loading - disassemblability - indirectness
- principle of force transmission - technology of joining
- data about type of section and material of elements of a joint

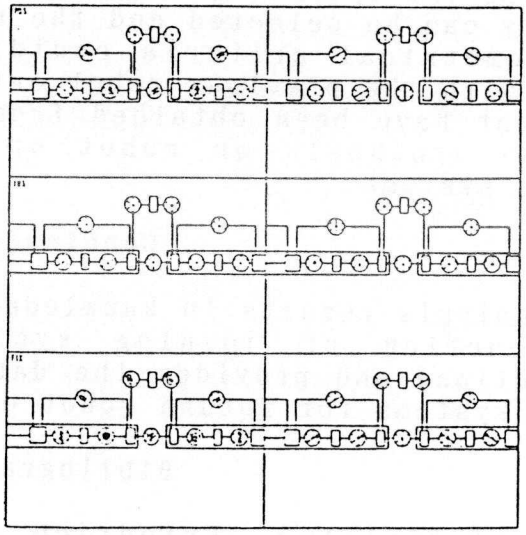


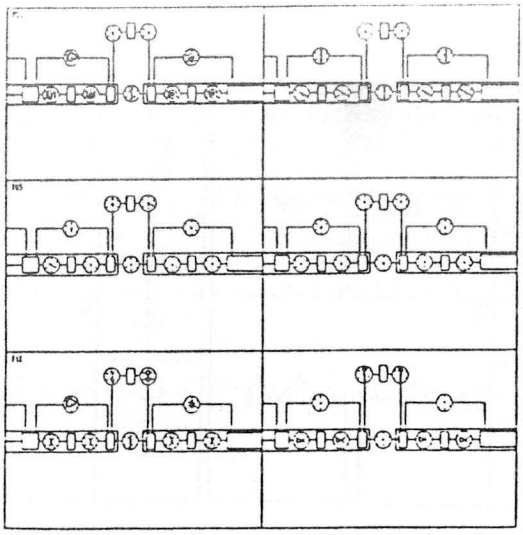
3rd Step

The concrete data of the joining system are transformed into a more abstract level. According to the guidelines of "Robot-oriented design" (2) the amount of elements are reduced:
-which are redundantly fulfilling the same function and
-which are redundantly used for manufacturing reasons.

The thus reduced joining system can be abstractly described by choosing graphical symbols. Structural graph shows the necessary informations on the assembly-sub-operations-positioning,adjusting, fixing-for the required movements. Supplementing the information on the motions during positioning and adjusting:
-relative motion during positioning between column and beam
-relative motion during adjusting between column and beam
Hereby it is assumed that the column is already positioned,adjusted and fixed.







4th Step

Here the effective principle of the joining system is shown Further functional reduction of the structural graph of the joining building group using following symbols. The functional structure is shown horizontally and vertically including all functional elements of the joining system. Each symbol represents a real building element or part.

Catalog
(To be set up in the future)

The various informations of the analysis can be comprised under functional ,physical,geometrical or operational aspects. For example a catalog can be set up containing all informations of the operation "positioning" from all described and analyzed joining systems. The same can be done for other operations "adjusting" and "fixing".

Therefore the operations which are mostly suited for robotic assembly can be selected and the related functional,physical and geometrical criteria could be choosen to optimally comply with the previous robot oriented operation. Now the data that have been obtained from the analysis can be used for the synthesis or robot oriented design process of joining systems.

Conclusion

This analysis results in knowledge basis about the structure and function of joining systems and their analysed subfunctions and provides the data for the establishment of expert systems for future robot oriented design.

Bibliography

(1) Prof.Dipl.Ing. Friedrich Hansen: Konstruktionssystematik, VEB Verlag Technik, Berlin, 1968.
(2) Dipl.Ing.T.A.Bock: Robot-Oriented-Design, 5th ISRC, Tokyo, 1988.