AUTOMATED REBAR CONSTRUCTIBILITY PROBLEMS DIAGNOSIS: A CONCEPT-PROVING PROTOTYPE

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ABSTRACT: The paper describes a rebar constructibility model, which was developed in an object-oriented graphic environment. The model is intended to be used during the design phase to automatically diagnose potential rebar-related constructibility problems (the Diagnosis Module), as well as to offer solutions and implement them (the Correction Module). The Diagnosis Module was implemented first in a concept-proving prototype. The proposed model searches for constructibility problems through all relevant parts of the building. This search includes the structural design, as well as other building systems.

Keywords: automation, constructibility, construction, design coordination, reinforcement, reinforced concrete.

1. INTRODUCTION

Rebar constructibility problems are discovered shortly before installation, or even after casting of the reinforced concrete (RC) element. As a result projects are delayed and their cost increases, rework is required, productivity is reduced, and the quality of the finished product is compromised.

One reason why rebar constructibility problems are discovered shortly before, or even after, construction is that in the present-day two-dimensional environment, checking a given design for these problems is difficult. This is possibly one of the reasons why it is not performed on a regular basis. This situation affects many members of the construction process: structural engineers who, as soon as a problem arises on-site, have to invest additional time to provide immediate alternative solutions, and who suffer damage to their reputation as well; contractors who absorb the cost overruns; and above all, owners who, in addition to the increased costs, must contend with delays and higher maintenance costs caused by defective RC products.

Several computerized systems for constructibility improvement have been developed [1, 2, 3]; none of them, however, deals with rebar. A rebar constructibility system that automates and improves the present-day procedures is clearly needed. Such a system should provide two important functions of constructibility analysis, namely, to detect potential constructibility problems in the early phases of a project life cycle, and then to find solutions for them [4]. The present paper describes the development of such a rebar constructibility model, which includes two modules. The first of the two is a Diagnosis Module, which analyses a given design and alerts the structural engineer upon discovering a problem. This module was implemented in a concept-proving prototype, and is the focus of this paper. The second module, the Correction Module, proposes solutions to the problems discovered by the Diagnosis Module and, if approved, applies them. The incorporation of the Correction Module into the prototype is currently in progress.

2. REBAR CONSTRUCTIBILITY MODEL

The proposed model is intended to be used during the rebar detailing stage to avoid "surprises" during construction (Fig. 1). The model assumes that the design is based on project modeling principles and is represented in an object-oriented (OO)

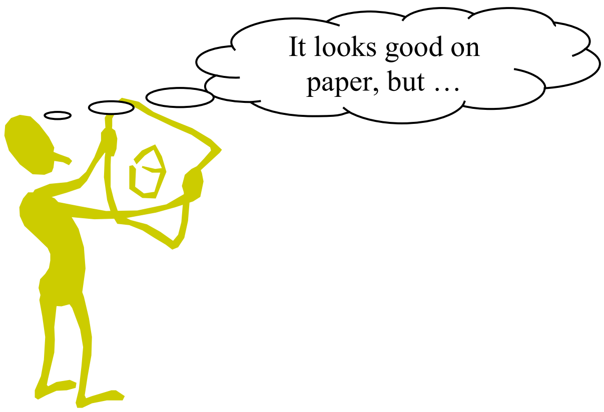

Figure 1. Present-Day Constructibility Diagnosis.

database (Fig. 2), which includes the up-to-date versions of the structural design, the design of the various building systems, and the design of temporary facilities, such as scaffolding and formwork.

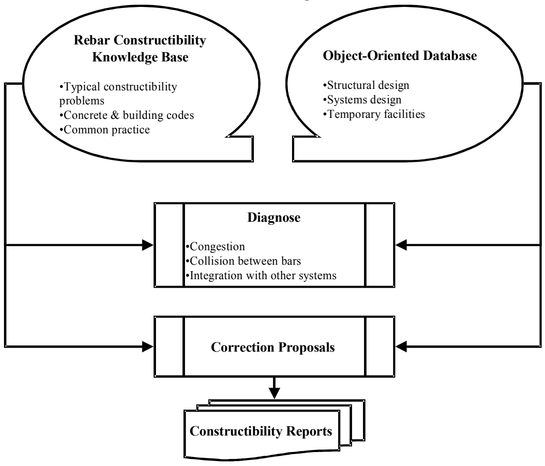

Figure 2. Rebar Constructibility Model

Extensive knowledge is required in order to identify constructibility problems and to propose solutions. This knowledge, included in the model, comprises a definition of the building systems or elements (e.g. drainage, electrical) that are to be checked together with the diagnosed structure, and the types of tests that the model is to perform in order to identify the constructibility problems. The knowledge is stored in an external knowledge base called "Rebar Constructibility Knowledge Base" (RCKB), which also includes a description of typical constructibility problems, relevant components of the pertinent concrete and building codes, and common practice. The advantage of using an independent external knowledge base is the ability to add knowledge or change it without changing the model itself.

Based on the data contained in the project model and the RCKB, the Diagnosis Module identifies rebar constructibility problems in a given design. Once constructibility problems have been identified, the structural engineer may modify the design, consult with the correction module for solutions to the problem, or, when pertinent, try to solve the problem in collaboration with other consultants.

3. THE BUILDING MODEL

A prototype system, which uses the Rebar Constructibility Model, was developed to examine the concept and demonstrate the feasibility of developing effective automated constructibility tools. A field survey to identify rebar constructibility problems showed that most of the problems appeared in beams. Consequently, the scope of the concept-proving prototype was limited to this element. For simplification, the system handles beams under the following assumptions:

- Beams are rectangular boxes.
- The relationship between beams is either parallel or perpendicular.
- Bars are planar (bent in one plane) and they, too, are either parallel or perpendicular.

The building model developed in the present study uses the AutoLISP++ development platform [5], which was written in AutoLISP® augmented by OO capabilities. The model defines the relationships between the building elements as well as their hierarchy, starting from the entire building down to the rebar itself (Fig. 3).

A Building can contain an unlimited number of Building Sections (e.g. floors or any other defined segment of the building). Each of these Building Sections comprises Building Assemblies, which are parent classes. Their children classes – other assemblies (here Structural, Drainage and Temporary Structures) – can serve one or more Building Sections (e.g. a drainage assembly serves all floors of the building). Each child class can have children classes of its own, e.g. Temporary Structure. The lowest level class contains the building elements, such as beams, which are the focus of this model.

Each beam contains a number of Rebar Layers, which is a group of reinforcement bars with a specific location or function (Rebar Collection), such as positive or negative reinforcement, stirrups, etc. These Rebar Collections can contain a number of bars of different shapes and diameters. Each bar can be part of a single layer or it can be common to a number of layers (e.g. a bent-up bar serving as positive reinforcement at the mid-span, and as negative reinforcement above the supports). At the lowest level of this model is the Rebar, which is one or more bars of common shape, diameter, and length.

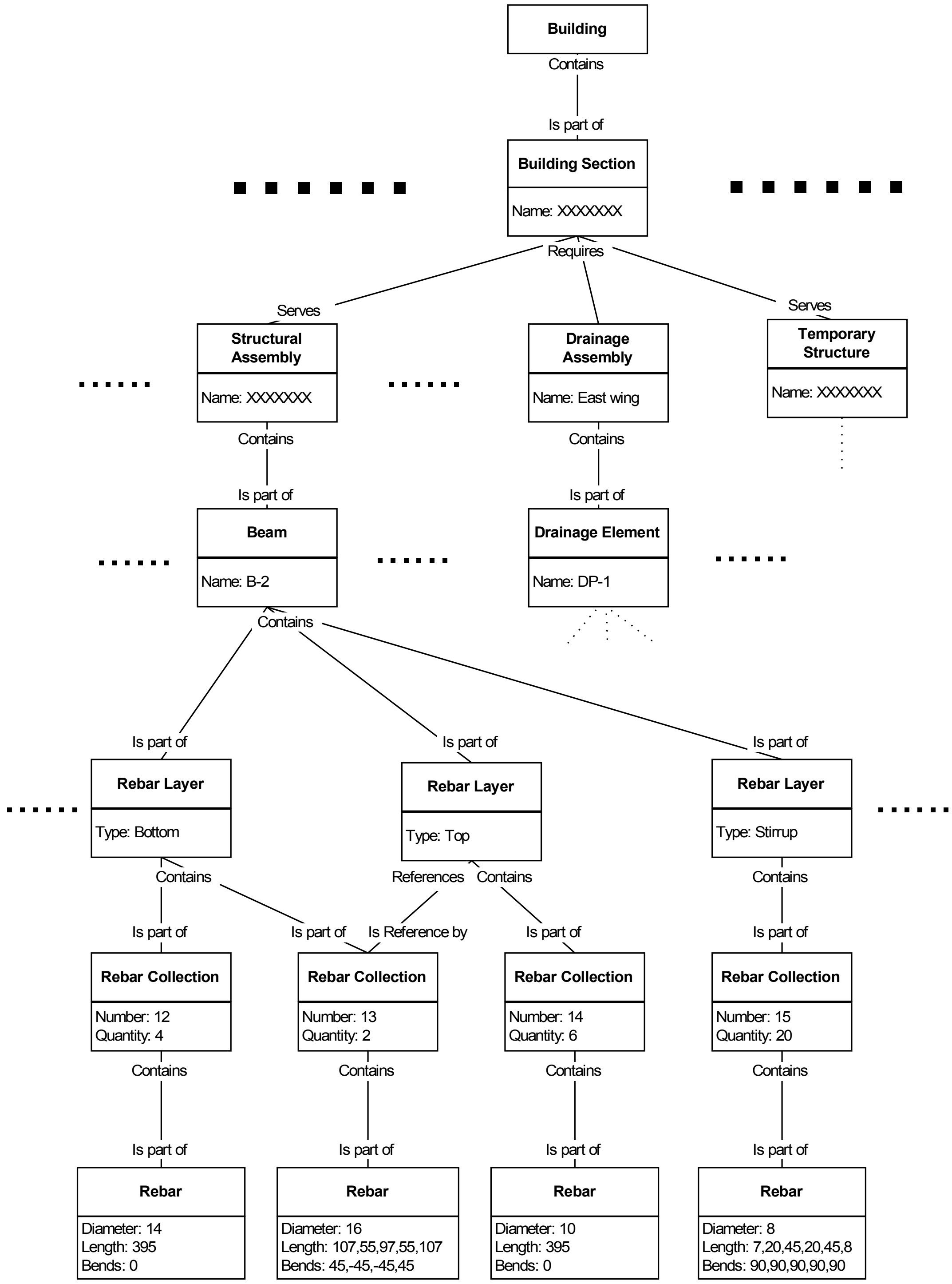

Figure 3. Building Model.

4. DIAGNOSIS MODULE

The Diagnosis Module analyzes a given design, detects rebar-related constructibility problems, and reports them to the structural engineer. The prototype was limited to the following constructibility problems: steel congestion, collision between reinforcement bars, problems caused by the integration of drainage or other systems (e.g. formwork) into the RC element, and checking for minimal/maximal reinforcement ratio.

The operation of the prototype system is demonstrated below for a building section containing two slabs, four beams with their reinforcement, and a drainage pipe, as shown in Fig. 4.

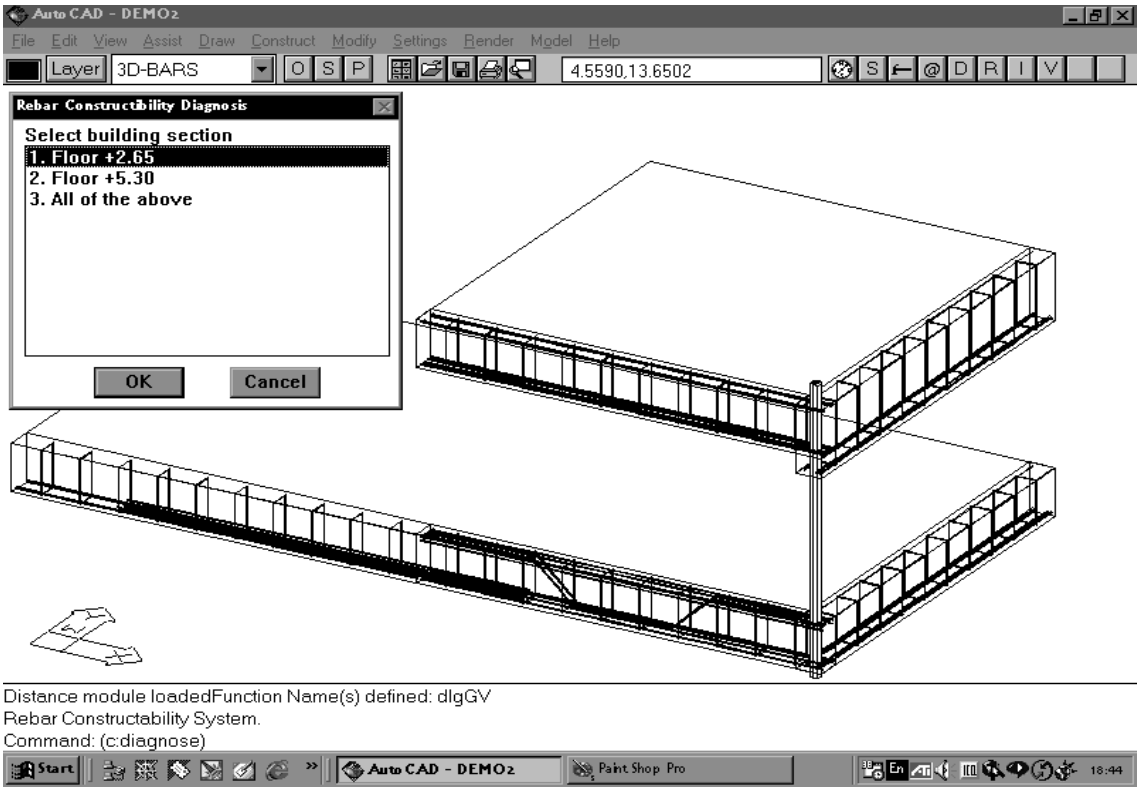

Figure 4. Building Section for Demonstration

4.1 General Description of the Module

The diagnosis begins with the extraction of a list of the available Building Sections from the Project Model. The structural engineer selects the Building Sections to be diagnosed, in this case slabs +2.65 and +5.30, each of which is diagnosed separately.

The analysis of each floor starts with the retrieval of the Structural Elements comprising the selected Building Section(s) relevant to the current analysis. Each element undergoes only the tests pertinent to it. This is made possible by the OO model, in which each element has its own "method". In the prototype, the tests for a beam are: a congestion test, a collision test between rebar and other elements, a test to ensure the correct concrete covering of bars, and a calculation of the reinforcement ratio. The output of the diagnosis is the Constructibility Report, which is given both in dialogue and in written formats.

4.2 Congestion Test

Rebar congestion, as a constructibility problem, can be avoided in many cases if, as part of standard designs, detailed cross-sections containing all bars are provided. These cross-sections are to be drawn for a number of critical points along the beam, mainly near the supports. In order to determine the existence of a congestion problem, the prototype calculates the distance between the centers of adjacent bars. The clear distance between adjacent bars is calculated according to the Israeli Concrete Code [6].

To avoid excess computation, the bars are divided into two groups. Group 1 contains all bars defined as "part of" the beam currently being diagnosed; Group 2 contains all bars of Group 1 as well as all bars defined as "passing through" this beam. Each bar in Group 2 is checked against each bar in Group 1. Thus the bars in Group 1 are checked against one another (as they appear in both groups), whereas the bars belonging to other beams (which will, in turn, be checked against one another when those beams are diagnosed) are checked only against the bars of the beam currently being diagnosed. Consequently, only the minimal number of necessary computations is performed.

4.3 Collision Test

When the distance between bars, or other building elements, is less than half the sum of their diameters (or another dimension for non-circular elements), the model reports a collision. The collision test is carried out for all relevant elements using the same function used, in the congestion test, for the calculation of the distance between elements, with the following differences:

- Group 2 includes elements such as HVAC conduits, formwork ties, etc., in addition to reinforcement bars.
- Data from the Knowledge Base is required here to determine the type of elements to be included in Group 2.
- The test is carried out for non-parallel elements (perpendicular in this case).

This test contributes not only to the determination of collisions between rebar elements, but also to the identification of problems caused by the integration of various building systems into the diagnosed beam.

4.4 Cover and Reinforcement Ratio Tests

The thickness of the cover (TC) is an important factor in protecting bars against corrosion. To perform the TC test, the system checks the maximal coordinates (in the beam's local coordinate system) in the X, Y, and Z directions and measures the distance from each coordinate to the envelope of the beam. This measurement is then compared with the minimal requirement according to the Israeli Concrete Code [6].

The system also calculates the minimal and maximal ratios of reinforcement for a given cross-section of the RC element, compares them with the requirement specified by the standard [7], and alerts the structural engineer if the value exceeds the allowed reinforcement ratio.

The detailed algorithms of the cover and reinforcement ratio tests (as well as all other algorithms presented above) are described in [8].

5. CONCLUDING REMARKS

It is all too often that rebar constructibility problems are discovered shortly before construction, or even after the reinforced concrete element has been cast, resulting in cost increase, schedule delays, and reduced quality. This situation can, and must, be rectified. A field survey conducted for the present study indicated that the problem is widespread. The field survey also mapped some of the key problems of rebar constructibility.

To overcome these problems, a model for rebar-constructibility diagnosis and correction was developed. The model can assist structural engineers in diagnosing their design and in offering solutions for potential constructibility problems, such as high congestion of reinforcement bars, collision between bars, and collision between bars and other building systems. As such, the model is essentially a design-coordination tool as well. A concept-proving prototype system was developed in order to verify the model and demonstrate its potential. The prototype was limited to dealing with rectangular beams, as deemed sufficient for the purpose of concept proving; its commercialization would require expansion to other RC elements. At this time, the prototype implements the first part of the model, namely the Diagnosis Module. The implementation of the Correction Module is currently in progress and is to be reported separately.

The study has demonstrated the feasibility of developing automated constructibility diagnosis systems. The main advantages of such systems are:

- Using the proposed model enables a considerable reduction of time otherwise consumed by manual constructibility review.
- The proposed model is better than present-day alternatives because it is a true three-dimensional diagnosis tool. Consequently it enables analyses that are difficult to achieve otherwise, e.g. congestion problems caused by the integration of beams and columns (such as the one depicted in Fig. 1), or problems caused by the integration of building systems (drainage pipes, HVAC ducts, etc.) with RC elements.
- Using the proposed model, even inexperienced structural engineers can produce much better designs.

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