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Proposal for reorganization of the connections chapter of Eurocode 5

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ABSTRACT

Designing a timber connection which is buildable with minimum errors has been considered the most difficult aspect of a timber design. Although many studies have been conducted in the past on various aspects of the usability of Eurocode 5, the authors felt that with the impending revisions to the Eurocodes, it was pertinent to ask the users for their opinions in a more focused manner, with questions aligned with the revision objectives. As part of the activities of the working group 3, “Connection” of the COST Action FP1402, a Europe-wide survey was thus conducted among the practitioners, where a number of questions related to Eurocode 5 in general and the connections chapter in particular was asked. The majority of respondents felt there were improvements to be made both to the technical content, as well as the usability of the standard in terms of clarity and ease of navigation. The results of the survey are summarized in this paper with a proposal for reorganization of the current technical content, which the authors feel answer the majority of the concerns raised by the users.

1. Introduction

Eurocode 5 is an integral part of the aimed European harmonization for product and design standards, allowing a common structural building market all around Europe. By setting common principles for design and construction, this harmonization aims to facilitate a smooth exchange of construction works and products across European borders. All of Eurocode 5 parts, numbering three in total, were published in 2004 after a long historical development which started in 1983 [1,2], although some previous work had already been done back in 1979 [3]. Eurocode 5 was originally based on the CIB “Structural Timber Design Code” (CIB, 1983), developed within the CIB-Working Commission W18 “Timber Structures”. However, since early stages, changes were made in order to provide “an operational code for direct use by the designers” [4]. A first version was published in 1987 as a report of the European Commission [5], and was open for national comments up to 1989 [6]. In 1990, the work was taken at the European Committee for Standardization (CEN), and a first version as a pre-standard (ENV 1995-1-1) was published in 1993. This version was already adopted by some countries, and it was the basis for the final version of EN 1995-1-1:2004, which was published in 2004, and implemented by all member states in 2010 [7]. Before voting and approval, the final version of EN1995-1-1 was sent out to practitioners by the National Standardization Bodies. However, it shouldn’t come as a surprise that the practitioners were not able to actively participate in the process due to commercial constraints.

It must be remembered that it was, for some European countries, the first ever code for timber structures. In addition to the publication of the standard, there was also the need for further guidance and commentary to the new standards, a need which was partially fulfilled by the STEP books [8,9].

In December 2012, through the Mandate M/515, the European Commission invited CEN to develop the work program for the preparation of the second generation of Eurocodes. The Mandate, among other objectives, called for a “Refinement to improve the ‘ease of use’ of Eurocodes by practical users” [10]. The CEN answer to the Mandate, “Response to Mandate M/515” [11], focuses on harmonization and state-of-the-art approaches and also on user confidence. The required ease-of-use has also been further clarified by defining that the Eurocodes are addressed to “Competent civil, structural and geotechnical engineers, typically qualified professionals able to work independently in relevant fields” [12]. Fundamental principles to achieve harmonization and long term confidence by the users were also identified as clarity and understandability, ease of navigation, state-of-the-art information, consistency with products and execution standards.

Within this context, the users’ point of view has therefore been of crucial interest in the development of the second generation of Eurocodes. Previous work by the European Confederation of

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Woodworking Industries (CEI-Bois) made a survey of stakeholders from European countries to find out the problems and needs in relation to the Eurocode 5 [13]. The findings summarized that there was no universal acceptance within the timber construction community [7]. The observed reluctance was partly attributed to the semi-probabilistic approach of the standard, which increased the need for use of non-transparent computer programs. Quite notably however, some significantly contradictory demands were also found out through the survey: while the majority of stakeholders asked for a simple and a reliable tool (standard), others demanded a more comprehensive design process for complex structures [7].

The section on connections, the Chapter 8, takes up a long part of the current version of the Eurocode 5. About 20% of the text is spent on connections, and yet, only the most common joint types are included in detail. In the former 1987 version [5] approximate expressions were used for connections, but the final version adopted the "Johansen model" [6]. Discussions related to the development of the model included in the final version of the Eurocode 5 may be found in the CIB-W18 proceedings [14].

The COST Action FP1402 aims to bridge the existing gap in the timber construction world between the broadly available scientific results and the specific information needed by designers, industry, authorities and code committees [15]. Its results will provide some background knowledge for the development of the so-called Second Generation of the Eurocodes, aimed to be produced in 2020 [7].

Within the Working Group 3 (WG3) of the COST Action FP1402, it was thus decided to develop a questionnaire to get the opinion of the practitioners about the content and structure of the current Chapter 8 of the Eurocode 5 [16]. The idea was to understand if the experiences of the practitioners, academia and manufacturers, the so-called stakeholders to the standard, were in line with the declared objectives the harmonization as a whole, and to identify any general problems and issues concerning Chapter 8 and Eurocode 5.

2. Questionnaire for practitioners about the connections chapter of the Eurocode 5

A questionnaire can be an excellent tool to get an insight into the problems faced by the practitioners. Were the problems related to the practitioners' lack of confidence in timber commercial and industrial projects due arising out of a number of contributory factors, including the lack of available information, lack of assistance with timber design, lack of tertiary timber engineering courses, lack of training for timber engineering and wood construction? [17–19]. Numerous studies had already been done in the past to gather consumer opinions towards timber as a construction material [20], architects' view on timber structures [21–23], trends in worldwide markets [24,25] and future potential of wood construction [26,27]. An Australian study [28] concluded that most practitioners are cautious about using timber and timber products, and that acquiring the necessary expertise in timber design and construction to be a medium to long-term proposition for the timber industry. On the other hand, practitioners also felt that there is a serious deficiency in any support given by the governments and that regulations are too stiff and conservative [21].

Design issues and related problems for the wider use of timber structures were presented in numerous papers: "Design issues for tall timber buildings" [29,30], "Design issues of timber structures in earthquake zones" [31], "Issues with execution standard" [32], "Design issues of the Eurocode 5 and revision process" [2,33], "Issues with the lack of reinforcements methods in the code" [34], "Issues with fire in timber structures" [35].

The design of connections in timber structures has long been identified as the most crucial component of the design process due to the complex stress transfer mechanisms exhibited by dowel type connections, the wood anisotropy, the potential for wood splitting arising out of excessive stresses perpendicular to grain, significant reduction of wood cross section in the joint region, lack of understanding of detailing and execution, manufacturing and construction [36]. A Nordic study presented in [37] identified that 23% of failures of timber structures were directly connected due to bad design of connections in structural elements and that in 57% of the cases reported failure occurred in dowel-type connections. As such, the design of timber connections is a priority in timber engineering research, education as well as in Quality Assurance procedures [36].

2.1. Methodology

An online questionnaire was prepared by the authors. Web-based surveys are increasingly common and are a cost-effective method to collect information [38]. Studies have found no significant differences between traditional mail-in questionnaires and web-surveys regarding the response rates and the quality of responses [39,40].

A draft version of the questionnaire was developed by the authors, which was then reviewed by experts from academia and industry involved in COST Action FP1402, WG3. An online version using the "Google Forms" application (https://gsuite.google.com/products/forms) was then developed in English, and was translated to several languages. Pre-testing was done through an expert group within WG3, which showed that there was no difficulty in completing the questionnaire. The resulting final survey was distributed to stakeholders in the member states.

The questionnaire was divided into four parts: general information about the respondents, general issues of EN 1995 [3], issues with Chapter 8 and specific issues with fasteners. The first part of the questionnaire asked information about the work experience in the field of timber structures, common types of structures and engineered wood products which are commonly used. The second part of the survey was focused on the general knowledge of the EN 1995 standard, in particular on the familiarity with the standard, possible problems, mistakes and issues of the standard, also asking for recommendations for improvement. Of interest was also to get knowledge about other standards or guidelines often used when information is not found in EN 1995. The third part was questions about satisfaction about the Chapter 8, problems and disadvantages. Questions were also asked about the organization of the Chapter. The fourth part asked about specific issues with fasteners. Overall, a total of 35 questions with 36 sub questions were asked (Table 1).

As previously mentioned, the main focus of the survey was to get the views of the practitioners. To target this audience better, the online questionnaire was translated into 12 different European languages (English, German, Spanish, Portuguese, Italian, French, Croatian, Slovenian, Slovakian, Estonian, Finnish and Dutch). Information was gathered in the above languages and later translated into English. Distribution of the survey was achieved via the participants of COST Action FP1402, and also the former COST Actions dealing with timber structures (FP1004, FP1101, E55). Survey was also circulated widely to the practitioners in Europe. In several countries the questionnaire was sent via Chambers of Civil and Structural Engineers.

All the response data was collected in google spreadsheets and later downloaded and analyzed using Microsoft Excel 2013 and Matlab tools (v.9.1). Standard statistical techniques were used. Descriptive statistics and charts were calculated.

Potential sources of errors and limitations of the research were in the sampling procedure, high level of survey fatigue, the length and complexity of the questions [41] or availability of e-mail addresses and respective response. Considering technical problems such as browser freeze which can result in missing data, the questionnaire can be considered very successful as only one person who didn't seem to finish the survey. Considering the sampling method, the participants were mostly from timber engineering practices, which was the goal of the survey and not the limitation. Although the number of respondents represents only small number of the population of interest, 412 responses can be

Table 1
Summary of questions and sub questions.

Topic	Type of response	No. of questions/No. of sub questions
General information	Multiple selection with possibility of open answer	4
	Dichotomous Scale	1
	Multiple choice	5
		10/0
General issues of EN 1995	Multiple selection	2
	Dichotomous Scale	1
	Five-point Likert Scale	4/3
	Open question	3
		10/3
Issues with Chapter 8 of EN 1995	Multiple selection with possibility of open answer	1
	Dichotomous Scale	4/6
	Five-point Likert Scale	2
	Open question	1
	Multiple choice	1/2
		9/8
Specific issues with fasteners	Multiple selection with possibility of open answer	1
	Dichotomous Scale	2
	Five-point Likert Scale	3/26
		6/26

accepted as a significant number considering the length of the survey.

2.2. Respondents' profile

The questionnaire was filled out by 412 respondents from 28 European countries and 5 non-European countries (Fig. 1). The survey collected basic demographic information regarding the respondents' location, work experience and continuous professional development on timber engineering. As seen from the Fig. 1, most answers came from Germany (23.8%), France (10.4%) and Spain (9.0%), but a significant number of responses came from other parts of Europe as well. Geographical location may have an influence on the final answers due to the state of development of the wood sector in respective countries.

Table 2
Respondents' professions (N = 412).

Occupation	Number of responses	Percentage [%]
Practitioner (design)	250	60.7
Academia	90	21.8
Practitioner (construction)	74	18.0
Manufacturer	67	16.3
Other	12	2.9

Note: Multiple responses were possible

Statistical analysis of data was done using the well-known statistical methods: the Mann–Whitney *U*-Test for features that had two variables, the Kruskal–Wallis *H*-Test for comparing more than two populations that are independent or not related and the Pearson correlation coefficient for the features where the answer was free or of numerical scale.

Only 7% of the respondents had less than 3 years of work experience and more than 64% had a work experience greater than 10 years. Regarding the work experience in timber structures only 11% had less than 3 years of work experience and more than 56% had experience greater than 10 years. More than 76% of respondents were working as practitioners and manufacturers, while 22% were coming from academia and 10% were from professions connected to the timber industry

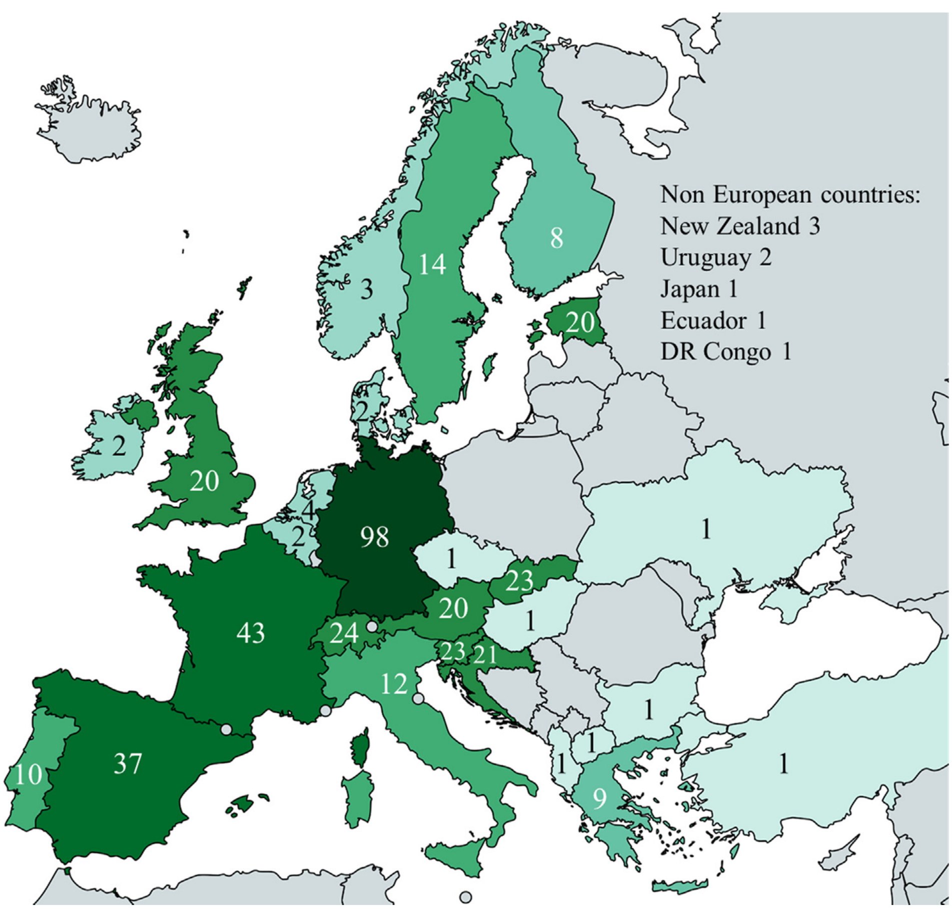

Fig. 1. Geographical distribution of the answers.

(Table 2). Numerous respondents reported more than one occupation.

Respondents were mainly working in medium to big design offices (with more than 10 employees) and in a respectful percentage of companies (40%) timber structures was their main point of interest, identified as having more than 70% of the daily work dedicated to timber structures. A great number of respondents had a experience in designing simple timber structures such as single family houses and timber frame houses (76%) or car ports and porches (59%), but there was a significant number of respondents who had experience in more complicated structures such as truss systems and long-span buildings (60%), multistory buildings (47%), buildings in cross laminated timber (43%) and pedestrian bridges (29%). Respondents were most experienced in timber structures made of glulam (90%), solid softwood (87%), cross laminated timber (59%), but also had experience in structures made of laminated veneer lumber (LVL) (42%) and solid hardwood (40%).

The above shows the quality of the answers and respondents' familiarity with the standard and timber structures, thus proving that the main goal of the questionnaire has been achieved. Of significant importance was that it was found that the majority of the respondents, although familiar with the standard, were not completely satisfied with it (Fig. 2). Using a 5-point Likert scale [42] from "I'm not familiar" (1 point) to "I'm really familiar" (5 points), the average grade for familiarity with the standard was 3.8 and for satisfaction only 3.0. Only 1.9% of respondents were completely satisfied with the code, which points to an underlying unease with using the standard.

To ensure quality of answers and to analyze only experts' opinions, special filters were applied according to Fig. 3. "Experts" were defined as respondents who had work experience of more than 3 year in timber engineering and are working in companies where every day work on timber engineering represent more than 40% of overall work. All of the answers were analyzed and an attempt was made to compare the responses from the groups, the experts and the non-experts, but the results were found to be similar with no clear difference between opinions expressed.

2.3. General issues of EN 1995

Inquiries on perceived general problems of Eurocode 5 and the need for improvement of the code were summarized in three descriptive questions where respondents could freely express their opinions on such matters as obvious mistakes in the code, parts that require excessive design effort to apply and parts that could lead to uneconomic construction. Altogether, 396 respondents used this option to express their opinions. A qualitative content analysis was conducted on their comments to classify them, as this method helps to group textual materials

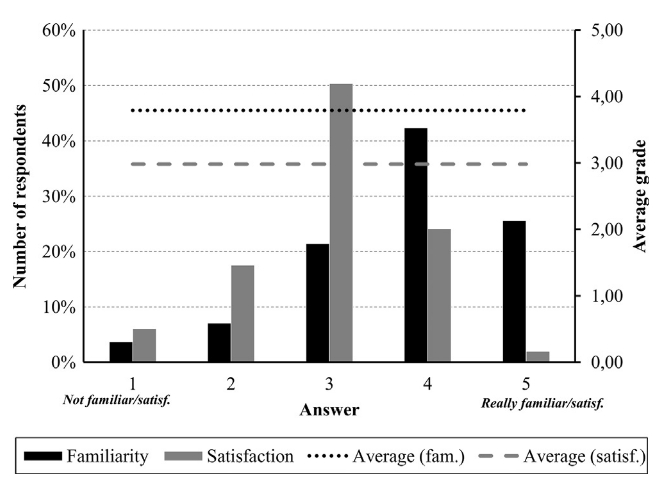

Fig. 2. Level of satisfaction and knowledge of the present Eurocode 5 (1 – I'm not familiar, I'm not satisfied at all, 5 – I'm really familiar, I'm pretty satisfied).

Fig. 3. Methodology for distinguishing experts and others.

into more relevant and manageable data [43]. For the question on obvious mistakes in Eurocode 5, some respondents interpreted correct expressions as wrong and complained about them. This points to the need for clarity in writing the standard. The most frequent answers were received however on the questions on excessive effort, uneconomic designs and on clauses where whole solution to the problem was not covered. These are summarized in Tables 3–6. Unsurprisingly, connections tops the lists in all these tables by some significant margins.

Using a 5-point Likert scale from "it must be changed completely" to "it doesn't need any change" only 6% of the respondents thought that the technical content doesn't need any change and 34% thought that it must be changed completely. Almost similar percentages had an opinion about the organization of the content, with 7% saying it doesn't need any change and 35% saying it must be changed completely. Huge dissatisfaction was found to be present in the perception of clarity and quality of figures, drawings and diagrams in the code, 5% siding with it doesn't need any change, but 40% siding with it must be changed completely.

A significant number of respondents were using the code for the design and/or checking of existing structures (62%). When there is a lack of information in Eurocode 5, respondents said they refer their former national standards, but also the standards of other countries (Fig. 4). Academics on the other hand tended to find information in scientific journals, guidelines or handbooks.

In general, opinion of respondents about Eurocode 5 is that the code is "full of unclear statements, lack of information and at times contradictions between chapters, and is not very transparent. This has proven to be too complicated even for the seasoned structural engineer. In practice, this reflects in poor quality of structural projects where design is not handled appropriately".

2.4. Issues with Chapter 8, connections of EN 1995

As seen from the previous Chapter and the Tables 3–6, most of the

Table 3
Parts in the EN 1995 that require excessive design effort to apply.

Topic	Frequency
Connections	64
Vibrations and deflections	14
Stability of members	12
Stresses perp. to grain and shear	8
Timber-concrete composites, components and assemblies	7
Load duration classes and service classes	7
Structural fire design	2
Seismic design	2

Table 4
Parts in the EN 1995 that that could lead to uneconomic construction.

Topic	Frequency
Connections	26
Stresses perp. to grain and shear	21
Stability of members	14
Structural fire design	13
Vibrations and deflections	13
Load duration classes and service classes	7
Material properties and partial safety factors	3

Table 5
Parts of the EN 1995 where whole solution of the problem is not covered or there is a lack of provided information.

Topic	Frequency
Connections	7
Cross Laminated Timber	5
Stability of members	4
Vibrations and deflections	4
Engineered Wood Products	3
Timber-concrete composites, components and assemblies	2

Table 6
Mistaken parts in the EN 1995.

Topic	Frequency
Connections	22
Stability of members	6
Stresses perp. to grain and shear	5
Vibrations and deflections	4
Load duration classes and service classes	3
Timber-concrete composites, components and assemblies	2

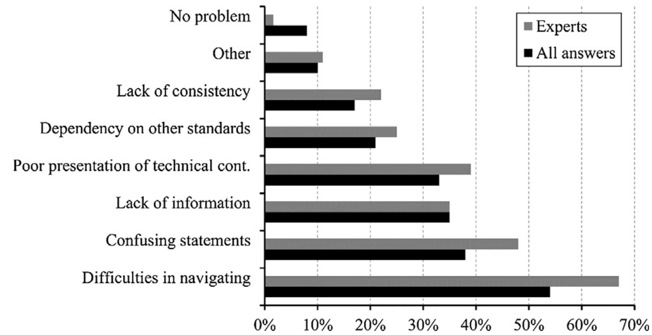

Fig. 5. Main problems with the current version of Chapter 8, EN 1995-1-1, (N_{all} = 410, $N_{experts}$ = 184).

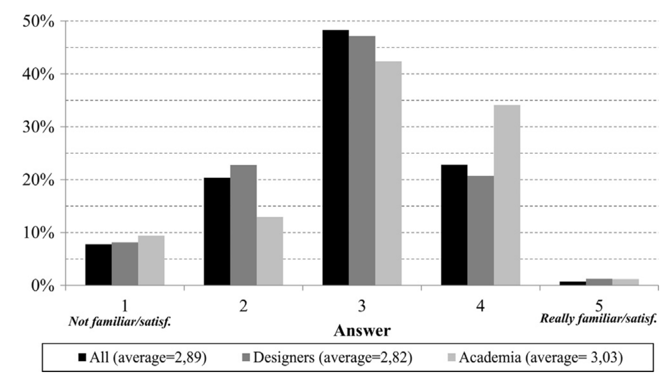

Fig. 6. Overall satisfaction with the structure of Chapter 8.

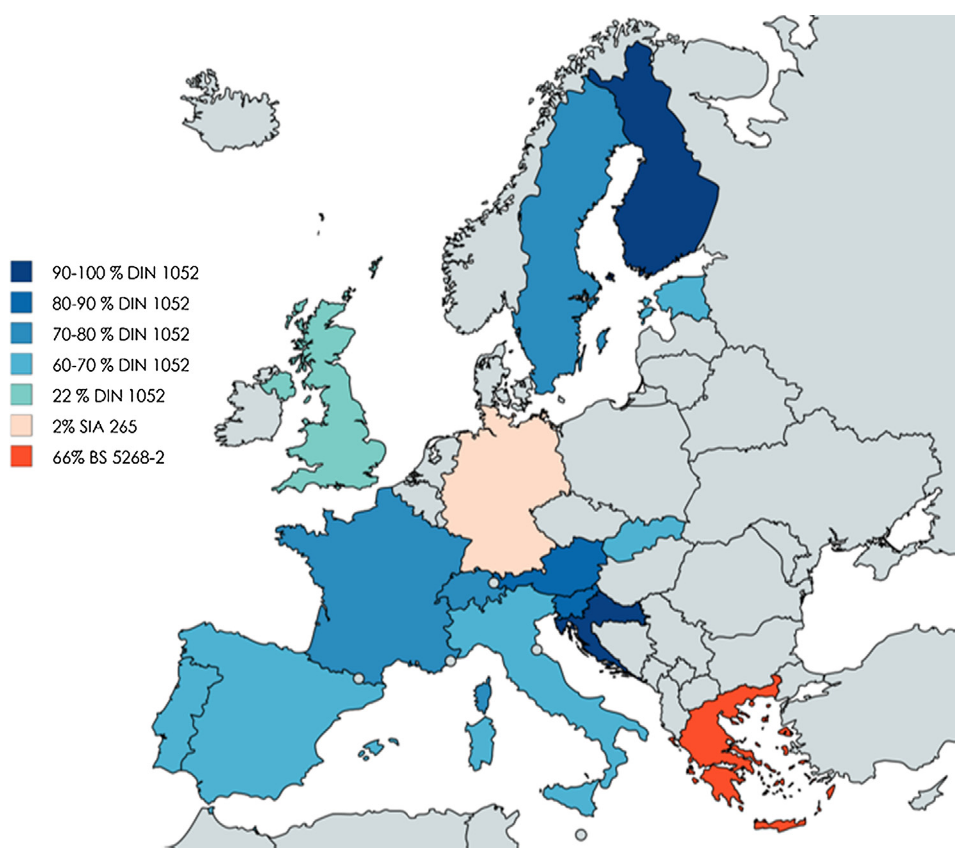

Fig. 4. If you don't find information in EN 1995 for a specific item of work, which other standard are you using?

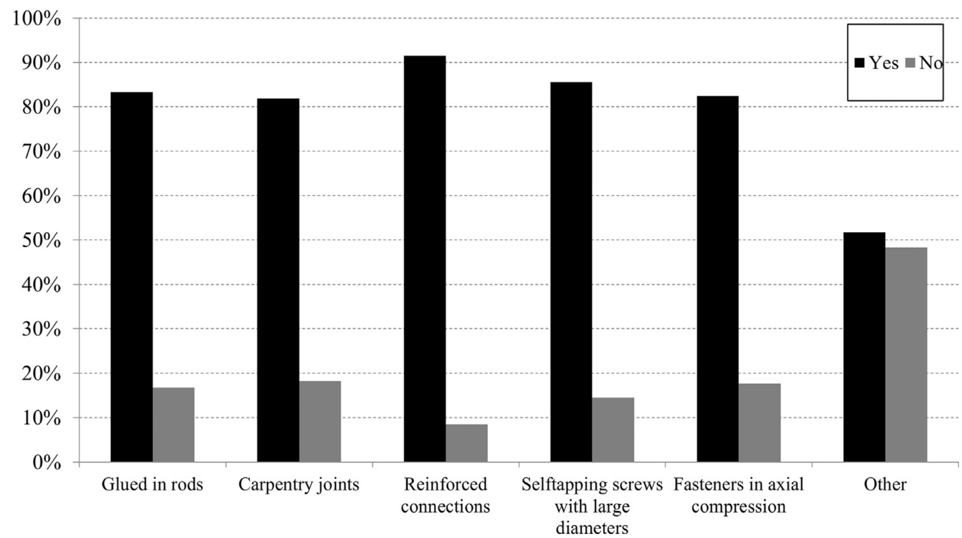

Fig. 7. What is missing and should be included in the Chapter 8.

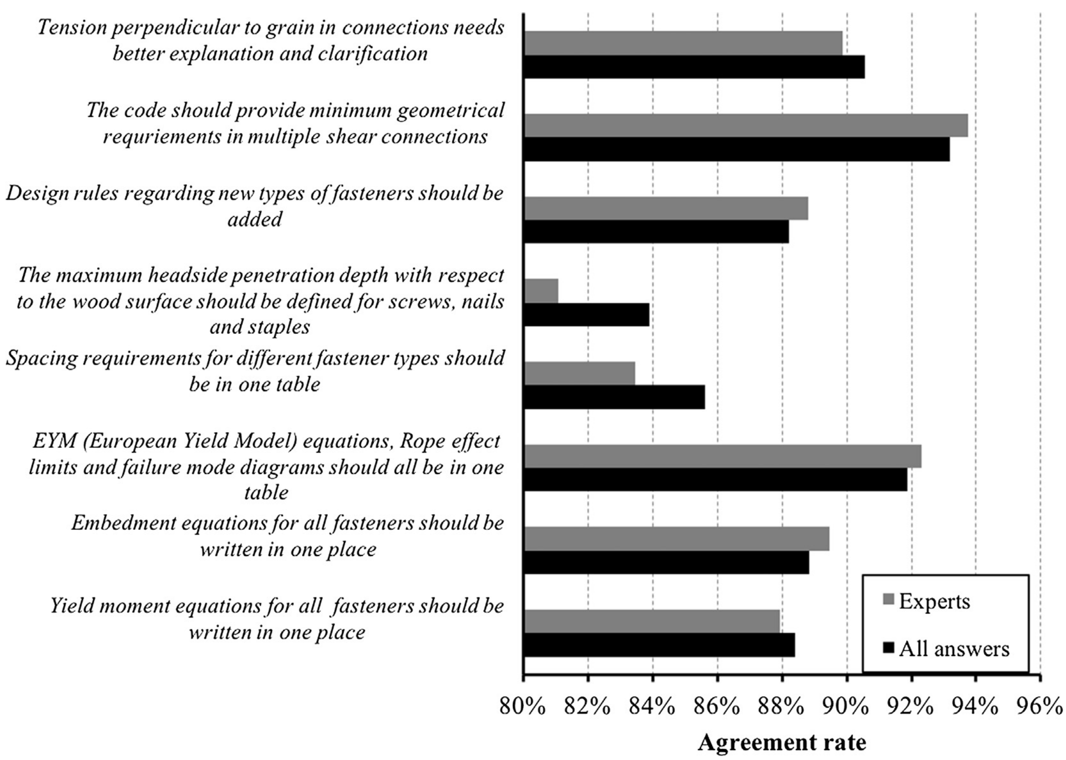

Fig. 8. Respondents' opinion about several questions of the reorganization of the Chapter (1 – I do not agree, 5 – I agree).

Table 7
Parts of Chapter 8 which should not be scattered inside the code.

Topic	Frequency
Spacing, end and edge distances	12
Johansen equations	6
Slip moduli and stiffness parameters	8
Mechanical parameters of dowel type connectors	8
Whole Chapter in general	7
Embedment strengths	3

problems were identified in the Chapter 8 of the Eurocode 5. The main problems with the current version of Chapter 8 are summarized in Fig. 5.

The most common opinions were regarding the problems in the structure of the code and difficulties in navigation through the Chapter. Confusing statements, lack of information, poor presentations of technical content, dependency on other standards and lack of consistency have also found to be presenting serious problem. In particular, the most common responses were:

- Design of connections is too complicated,
- Chapter 8 is too confusing,
- Spacing, end, edge distances are too complicated, unclear and require excessive design effort,
- Scrolling back and forth between the pages and also between the main standard and the national annex annoys and costs lot of time,
- There are too many cross references, within the standard as well as with product standards.

Table 8
Existing and proposed structure of Chapter 8.

Existing EC 5	Proposed new structure for EC 5
8.1 GENERAL	**8.1 GENERAL**
8.1.1 Fastener requirements	8.1.1 Fastener requirements
8.1.2 Multiple fastener connections	8.1.2 Timber requirements
8.1.3 Multiple shear plane connections	8.1.3 Multiple fastener connections
8.1.4 Connection forces at an angle to the grain	
8.1.5 Alternating connection forces	
8.2 LATERAL LOAD-CARRYING CAPACITY OF METAL DOWEL-TYPE FASTENERS	**8.2 DESIGN BASIS**
8.2.1 General	8.2.1 General
8.2.2 Timber-to-timber and panel-to-timber connections	8.2.2 Alternating connection forces
8.2.3 Steel-to-timber connections	8.2.3 Limits for joint capacities
	8.2.4 Miscellaneous rules
8.3 NAILED CONNECTIONS	**8.3 FASTENER PROPERTIES**
8.3.1 Laterally loaded nails	8.3.1 General
8.3.2 Axially loaded nails	8.3.2 Correction for wood type
8.3.3 Combined laterally and axially loaded nails	8.3.3 Strength parameters
	8.3.3.1 Embedment strength
	8.3.3.2 Yield moment
	8.3.3.3 Head pull-through strength
	8.3.3.4 Withdrawal strength
8.4 STAPLED CONNECTIONS	**8.4 DURABILITY**
	8.4.1 Corrosivity of timber and atmospheric environment
8.5 BOLTED CONNECTIONS	**8.5 SINGLE FASTENER CAPACITY**
8.5.1 Laterally loaded bolts	8.5.1 General
8.5.2 Axially loaded bolts	8.5.1.1 Combined laterally and axially loaded fasteners
	8.5.2 Axial load-carrying capacity
	8.5.3 Lateral load-carrying capacity
	8.5.4 Rope-effect
	8.5.5 EYM (European yield model) contribution
	8.5.5.1 Timber-to-timber and panel-to-timber joints
	8.5.5.2 Steel-to-timber connections
	8.5.5.3 Multiple shear plane connections
	8.5.6. Conditions for joint capacities (execution)
8.6 DOWELLED CONNECTIONS	**8.6 CONNECTION DESIGN**
	8.6.1 Spacing
	8.6.2 Group effect
	8.6.3 Timber failure
	8.6.3.1 Block shear and plug shear, steel-to-timber connections
	8.6.3.2 Connection forces at an angle to the grain
8.7 SCREWED CONNECTIONS	**8.7 SERVICEABILITY**
8.7.1 Laterally loaded screws	8.7.1 Joint slip (stiffness)
8.7.2 Axially loaded screws	
8.7.3 Combined laterally and axially loaded screws	
8.8 CONNECTIONS MADE WITH PUNCHED METAL PLATE FASTENERS	**8.8 CONNECTORS**
8.8.1 General	8.8.1 General
8.8.2 Plate geometry	8.8.2 Split ring and shear plate connectors
8.8.3 Plate strength properties	8.8.3 Toothed-plate connectors
8.8.4 Plate anchorage strengths	
8.8.5 Connection strength verification	
8.9 SPLIT RING AND SHEAR PLATE CONNECTORS	**8.9 PUNCHED METAL PLATE FASTENERS**
8.10 TOOTHED-PLATE CONNECTORS	

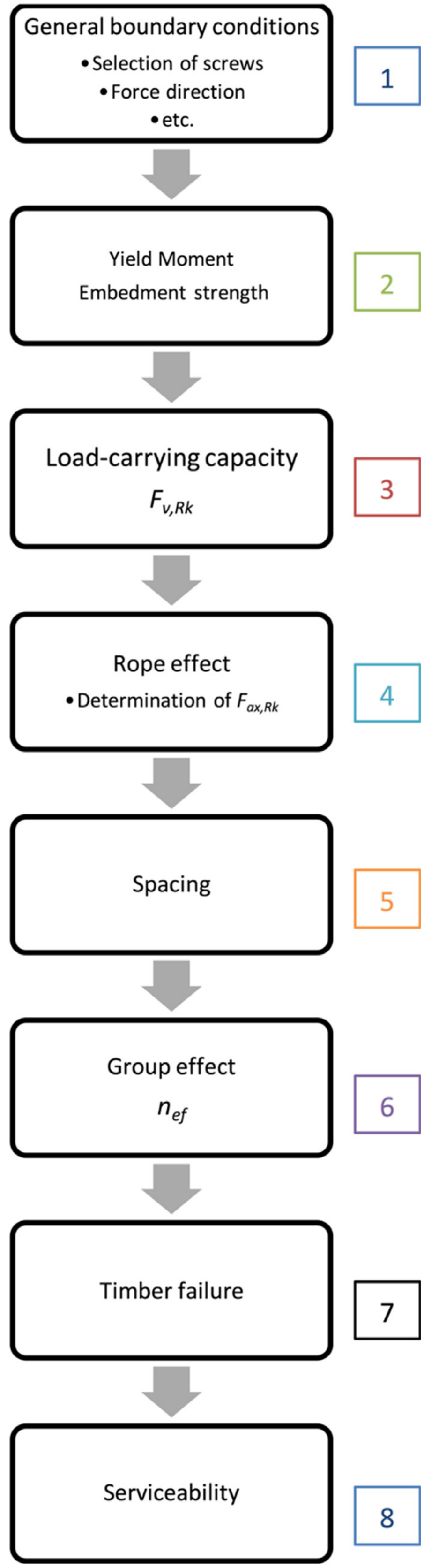

Fig. 9. General procedure for the design of a connection with screws.

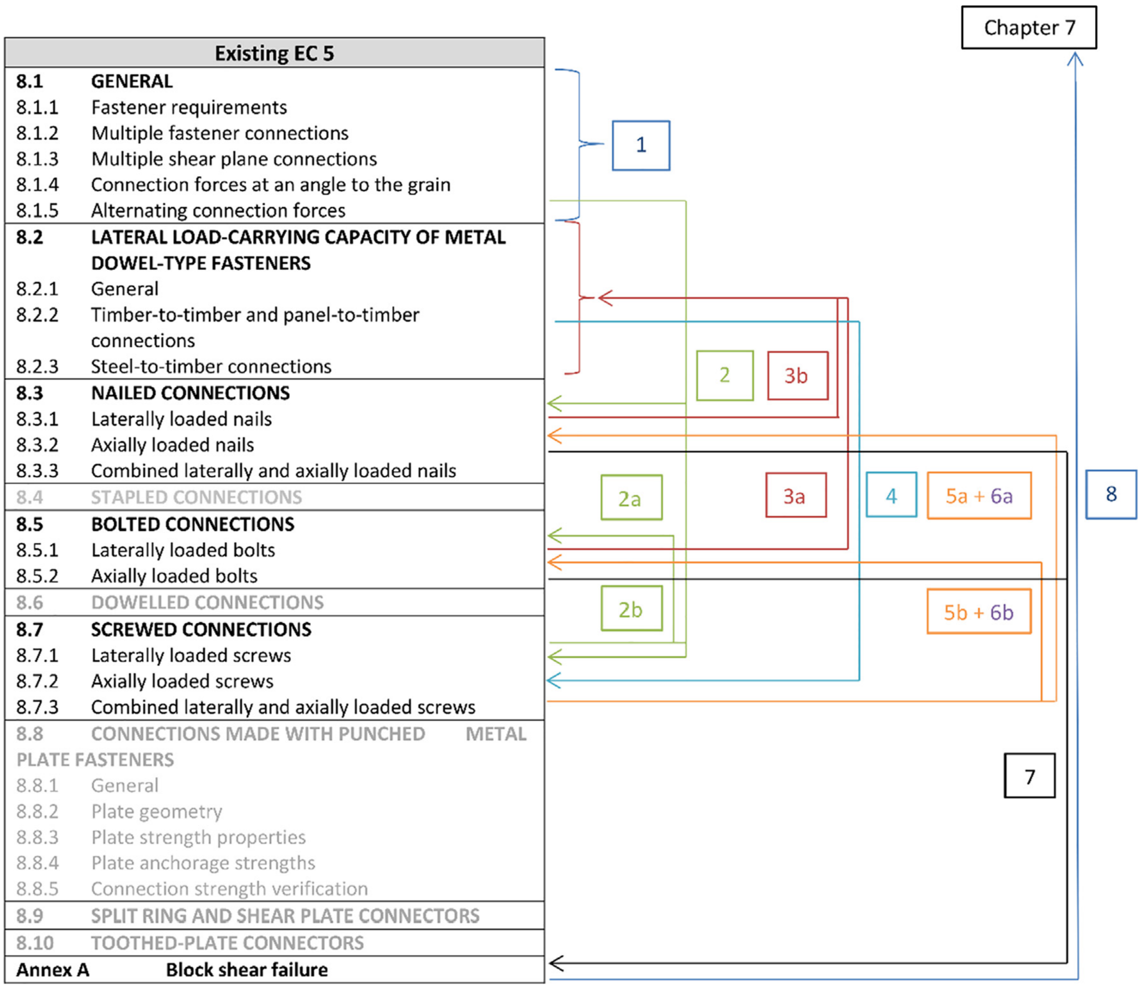

Fig. 10. Example of designing the lateral load-carrying capacity of a connection with screws – procedure in existing EC 5.

Using a 5-point Likert scale from "I'm not satisfied" to "I'm satisfied", academics with an average of 3.0 were more satisfied than practitioners with an average of 2.8. This can be seen in the Fig. 6. Only 0.5% of the respondents are completely satisfied with the structure of the code.

Fig. 7 shows the results of the responses received for the question about the missing information in Chapter 8. More than 80% of the respondents agree that there are a lot of missing details, such as on glued-in rods, carpentry joints, reinforced connections, self-tapping screws with large diameters and fastener in axial compression. They consider that design rules regarding new types of fasteners and connections in Engineered Wood Products (EWP's) should be added. Other things highlighted as missing in the Chapter 8 were; the rules for moment transmitting joints and modern screws, improved rules for effective number of fasteners and methods for calculation of slip in joints, combined effects of lateral and tension loads, new and brittle failure modes, better explanations of methods for obtaining ductility in the joints, etc. 55% of the respondents did not consider spacing rules as understandable!

From a practical point of view respondents agree that parts of the Chapter such as punched metal plate connectors, minimum spacing of fastener dependent on the density, tension perpendicular to grain, geometrical requirements in multiple shear and spacing requirements are too complicated or too confusing and better explanations and clarification of the problems are needed. Also, nearly 50% of respondents experience problems with the definition of loaded and unloaded edges for distances, differentiation between thin and thick plates (steel-to-timber connections), rope effect, explanation of fastener capacities for double shear, i.e., practitioners forgetting to multiply by 2 etc. Referring to other standards and mentioning of test standards for determination of characteristic capacities of fasteners were also raised as negatives. Regarding the reorganization of the Chapter, all respondents agree on the following statements: yield moment equations for all fastener types should be written in one place, embedment equations for all fasteners should be written in one place, Johansen equations, rope effect limits and failure mode diagrams should all be in one table, spacing requirements for different fastener types should be in one table (Fig. 8). Other parts that should not be scattered inside Chapter 8 were identified as slip moduli and stiffness parameters, spacing, end and edge distances for dowel type connectors (Table 7). Where possible, the figures and corresponding equations should also be next to each other.

A majority of respondents (56%) would prefer to use technical classes for fastener properties instead of declared properties and a huge majority (82%) wish there were more simple design rules for connections in addition to existing rules. An even greater percentage (88%) express the need and an interest in European Guidelines for the Chapter 8 of Eurocode 5, by way of technical background to the clauses, additional guidelines (like handbooks), examples and/or Eurocode 5 software.

3. Structure of the Chapter 8, EN1995

As shown in part 2.4 of this article one of the key items that surfaced as a result of the questionnaire was that the structure of the current Chapter 8 in Eurocode 5, which was partly a result of the TC250

Proposed new structure for EC 5	
8.1	**GENERAL**
8.1.1	Fastener requirements
8.1.2	Timber requirements
8.1.3	Multiple fastener connections
8.2	**BASIS OF DESIGN**
8.2.1	General
8.2.2	Alternating connection forces
8.2.3	Limits for joint capacities
8.2.4	Miscellaneous rules
8.3	**FASTENER PROPERTIES**
8.3.1	General
8.3.2	Correction for wood type
8.3.3	Strength parameters
8.3.3.1	Embedment strength
8.3.3.2	Yield moment
8.3.3.3	Head pull-through strength
8.3.3.4	Withdrawal strength
8.4	**DURABILITY**
8.4.1	Corrosivity of timber and atmospheric environment
8.5	**SINGLE FASTENER CAPACITY**
8.5.1	General
8.5.1.1	Combined laterally and axially loaded fasteners
8.5.2	Axial load-carrying capacity
8.5.3	Lateral load-carrying capacity
8.5.4	Rope-effect
8.5.5	EYM (European yield model) contribution
8.5.5.1	Timber-to-timber and panel-to-timber joints
8.5.5.2	Steel-to-timber connections
8.5.5.3	Multiple shear plane connections
8.5.6.	Conditions for joint capacities (execution)
8.6	**CONNECTION DESIGN**
8.6.1	Spacing
8.6.2	Group effect
8.6.3	Timber failure
8.6.3.1	Block shear and plug shear, steel-to-timber connections
8.6.3.2	Connection forces at an angle to the grain
8.7	**SERVICEABILITY**
8.7.1	Joint slip (stiffness)
8.8	CONNECTORS
8.8.1	General
8.8.2	Split ring and shear plate connectors
8.8.3	Toothed-plate connectors
8.9	PUNCHED METAL PLATE FASTENERS

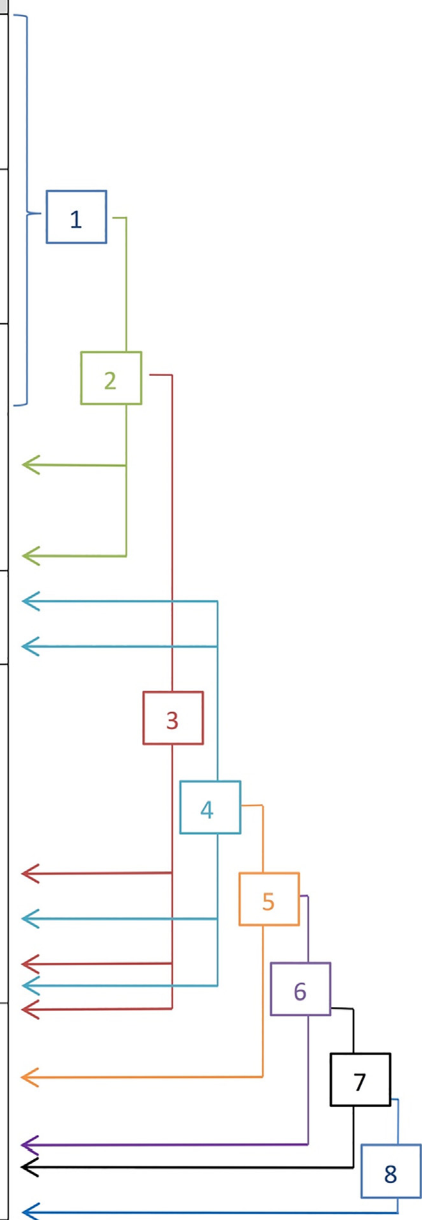

Fig. 11. Example of designing the lateral load-carrying capacity of a connection with screws – procedure in proposed version of EC 5.

requirement to have uniformity across different material design standards, is unacceptable for the daily use of the standard in practice. Therefore, a new structure to the Chapter 8 of Eurocode 5 is considered necessary.

The following table (Table 8) shows the existing structure of Chapter 8 against a proposal that came out of many discussions during WG3 meetings. The aim was it to get a structure which the designer can logically follow through from the beginning to the end, according to the steps involved in calculating the load carrying capacity of a connection.

In the first two sections some general information and rules for the basis of design are given.

The third section includes the fastener properties which are needed for the next steps. Section 4 has been retained as the one that discusses durability as it reflects the structure Eurocode 5. The capacity calculation of a single fastener is attempted first in part 5, as this forms the basis for the connection capacity later-on in the calculation. In contrast to the old structure, in the proposal fasteners are not differentiated by the type, but their diameter. Section 6 is new as it deals with the design of a connection. Within this section spacing, group effects, timber failure, block-shear, plug shear and forces at an angle to the grain are all considered. Section 7 covers the serviceability aspects. Traditional connectors and punched metal plate fasteners have been moved to Sections 8 and 9.

It is the authors' view that the proposed new structure to the connections chapter of Eurocode 5 is more in line with the design philosophy of a connection in practice, and that it makes the navigation through the chapter much easier.

Furthermore, the order of the sub sections of the chapter has also been changed, the benefits of which become quite evident when shown through an example of designing the lateral load-carrying capacity of a connection with screws (Figs. 9–11).

In steps 1–8 in the diagram in Fig. 9, the approach taken when designing the lateral load-carrying capacity of a connection with screws is described. When this approach is superimposed on the existing chapter (Fig. 10), it becomes very clear how confusing the current structure can be. In the proposed structure on the other hand, the design logic in steps 1–8 is broadly followed (Fig. 11).

These findings and the proposal was presented to the working group 5, responsible for the connections chapter, within the main CEN Structural Committee 5 (CEN TC250/SC5/WG5) responsible for timber engineering and therefore the committee that looks after Eurocode 5.

4. Conclusions

Designing a connection and realizing this design in practice has long been considered as one of the most important and the most challenging aspect of timber design. It has been shown that most failures occurring in timber structures were caused by human errors associated with the connection design. Although, human error is the predominant cause of most failures, incomprehensible, insufficient and/or inadequate statements in the standard do not help and just lead to unintentional and accidental human errors.

CEN/TC250/SC5, in "Response to Mandate M/515" [11], focuses on further harmonization of design principles, inclusion of state-of-the-art design approaches and enhancing user confidence in using the standard as priorities to be achieved in the next revision to Eurocode 5. In this regard, clarity and understandability, ease of navigation, state-of-the-art information and consistency with product and execution standards have been identified as key elements to the next revision.

A Europe-wide survey of practitioners, from both the industry and the academia was thus conducted to identify the end-user's perspective on the standard, especially in relation to the above key elements. The survey was prepared to cover Eurocode 5 in general and more specifically the connections chapter. The survey was translated into 12 European languages to broaden the feedback received.

The section on connections, the Chapter 8 of the current Eurocode 5, takes up a significant number of pages, which is in line with the importance of the section. However, through the survey conducted and the results discussed above, it could be seen that significant gaps still exist within this section. A clear understanding of the problems that everyday practitioner is facing when using this standard to design timber structures has been gained. Respondents to the survey agree that the Chapter is full of confusing statements, lacking in information and contain poorly presented technical content, making it difficult to navigate through and use. Most felt that the Chapter to be unacceptable due to its difficult navigation for day-to-day use in design practice, where the commercial pressures do not allow much time to complete a design.

A new structure to the Chapter has therefore been presented. Most of the user concerns that were found through the survey has been taken into account in preparing this proposal. Through the use of a simple example, the design flow of a simple connection has been studied, and the benefits are examined with a comparison to the existing structure of Chapter 8.

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