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THE FAMILIARITY WITH AND THE USE OF DISASSEMBLY-SUPPORTING CONNECTIONS AND FASTENERS IN GERMANY'S MANUFACTURING INDUSTRY – A SURVEY

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1. Introduction, Aims and Objectives

The process of disassembly is critical for the economic efficiency of the recycling of technical products. Disassembly does not only play an integral role in recycling, however. It earns as well great importance in production and assembly (when e.g. exchanging defective parts), during use (when e.g. removing packaging and shipping locks) and in maintenance (when e.g. replacing wearing parts). This leads to the necessity of considering aspects of connection technology - as an decisive disassembly factor - as early as possible during the development process. The selection and optimal design of connections is a difficult design task. It requires extensive knowledge about the available fasteners and connecting processes, a management of conflicting aims such as manufacturing and assembly requirements and recycling and disassembly requirements [Bauer 1991; Birkhofer & Schott 1996]. The effort of releasing a connection is highly dependent on the type of connection and is determined by release force and time and the complexity of release motions [Kahmeyer & Rupprecht 1996]. The disassembly-supporting connections facilitate the disassembly by simple actuation and easy and quick joining or releasing at low force or torque over short distances or angles [Schmidt-Kretschmer 1994].
Only for a fraction of the large variety of connections, the necessary knowledge exists and is published in standards and guidelines. Examples are: bolts, welded and glued connections. The use of disassembly-supporting connections (for details see [Klett et. al. 2002]) is limited to a few special application areas where requirements on the connections are not high, e.g. because they are subjected to small loads. However, there is a potential for a wider application. We hypothesise that these connections are hardly used, because they are not well known, information about their properties is not available and experience with their use is not existent. The aim of our study was to confirm or to rebut these assumptions. The aim was not to provide detailed explanations, but rather to describe the existing situation in order to obtain a sound base for the necessary research into disassembly-supporting connections.

2. The Problem

Our main assumption is that "Disassembly-supporting connections are not used in practice because the connections and their properties are not known." Our study aimed at the verifying this assumption and finding the underlying reasons. For this a number of research questions were derived from the assumptions. These research questions determine the variables on which the research process should focus, which in turn determines the most suitable research methods. The following research questions need answering:

- To which degree are disassembly-supporting connections known;
- To which degree are disassembly-supporting connections used;
- To which degree are conventional connections applied;
- What are the main reasons for a possibly non-consideration of disassembly-supporting connections.

3. Methods

To answer the formulated questions the following methods from the social sciences are useful:
- observation of individuals or groups undertaking the activity to be investigated;
- interviewing the individual or group about their activity;
- analysis of the designs and documents generated by the designers.

An overview of units of analysis and methods used in the social sciences gives [Atteslander 1995]. For overviews of methods used to analyse design activity, see e.g. [Blessing 1994; Frankenberger et. al. 1998; Lindemann 2003]. For some general recommendations for the appropriate application of social sciences' empirical methods in the area of design research and for some fundamental considerations referring to our own experiences in this area see [Bender et. al. 2002].

3.1 Design of the study

Because observations are difficult and time-consuming, a survey was selected as the most appropriate method to collect the necessary information. For reasons of time and economy and due to the large geographic distribution of the potential participants of the study, a postal survey was chosen. The comparability of the measuring situation can be assured by standardised questionnaires and the added cover letter. Moreover, the temporal pressure is cancelled on answering the questions and because of the guarantee of anonymity at a postal questioning, the likelihood of answering certain questions can be enhanced [Dillman 2000]. Up until now, very few data exists on this topic. So a primary survey realised as a cross-sectional study was necessary.

3.2 Sample design

The designer is responsible for the selection, layout and design of connections in technical products. Therefore, the group of designers of the manufacturing industry within Germany was chosen as the population to be surveyed. Because it was difficult to contact the "right" designers in the companies directly, the instructions of the questionnaire had to be carried out carefully. The design departments of the companies had been contacted and asked to deliver the questionnaire to the most appropriate person. Suitable companies could be found in an industrial company database sorted by economic activities, seen here as the creation of specific goods or services by combined use of resources such as equipment, labour, manufacturing techniques, information networks or products [cf. Rat der EG 1993]. This database contains companies of the manufacturing industry in Germany categorised according to the classification of economic activities of the Federal Statistic Office [Statistisches Bundesamt 1993]. From the whole sector of manufacturing industry the main economic activities showed in Figure 1 were chosen.
The outcome of this is a population of 25412 companies. Sample selection is crucial for the quality of results. To get a well-balanced proportion of effort and cost on the one hand and adequate accuracy on the other, the minimum sample size was determined at 384 companies with a confidence interval of 95%, an absolute error of 5%, and an assumption of the worst statistical spread [Böltken 1976, p147]. To compensate failures through incorrect information in the database, the sample size was increased by 25%. From the frame population a disproportional and stratified sample – stratified by sub-sectors of the main economic activities – was drawn. To have an adequate number of cases for the analysis of subsets, the minimum sample size per sub-sector was set to 10 companies. In result, we came up with a sample size of 555 companies.

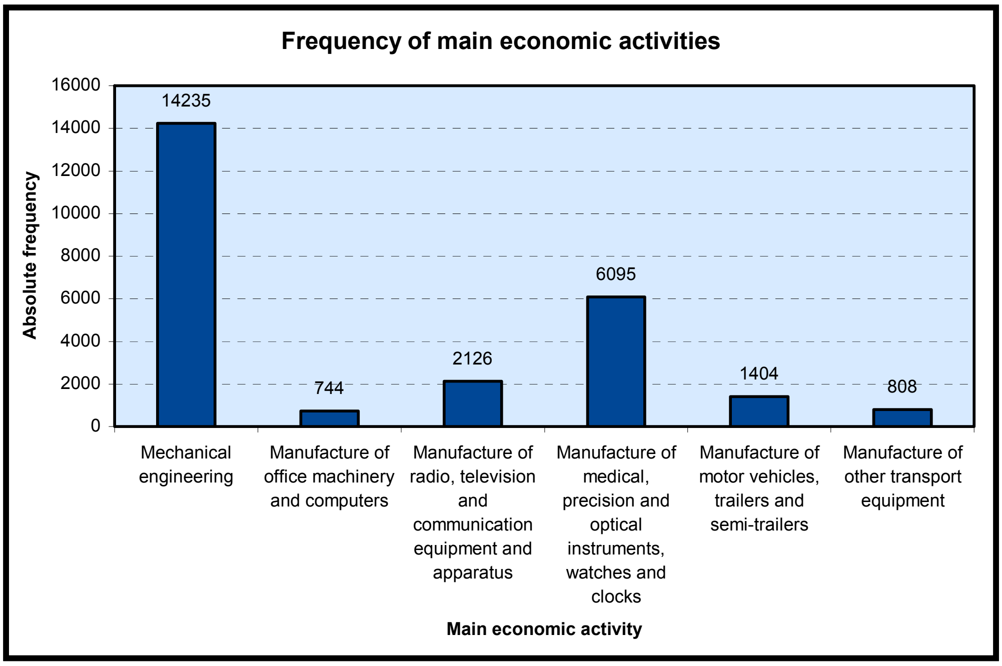

Figure 1. Distribution of main economic activities of Germany's industry in the population

Due to sample-neutral failures (e.g. defunct or non-reachable companies or companies which assigned themselves to the wrong economic activity) 36 companies had to be withdrawn from the study. Therefore the final sample-size was 519.

3.3 Design of the questionnaire

As mentioned above, the data was collected using a postal questionnaire. Particular attention was concentrated on the expected limited time-resources of the participants of the study. The difficulties consisted of the limitation of the number of questions to simultaneously gain a maximum yield of information on the one hand and of the interest-waking, clear, target-group-specific formulation of short questions with default answers (where possible) on the other to increase the motivation and to minimise the editing effort. Therefore, an elaborate pilot-study comprising extensive interviews and pre-questionings was executed among designers to get consistent and complete default answers on the mainly closed questions. The questions and answers had to be formulated in a way that they possibly did not lead to collisions with the participants obligation to maintain secrecy.
Some additional questions were added to the questionnaire to find out the function of the person who completed the questionnaire and to collect some additional information about the company.

4. Procedure

The questionnaire was sent with a cover letter to the companies. Two weeks after shipping the questionnaires, a first reminder postcard was posted to all respondents which contained acknowledgements in case that the questionnaire had already been sent back, and a reminder to take part in the survey if it had not. At the end of the fourth week another reminder with a substitute questionnaire enclosed was posted. Within 50 days 196 of the 519 companies responded, so that the overall response rate was approximately 38% (Figure 2). Thus, the survey can be assessed as a success.

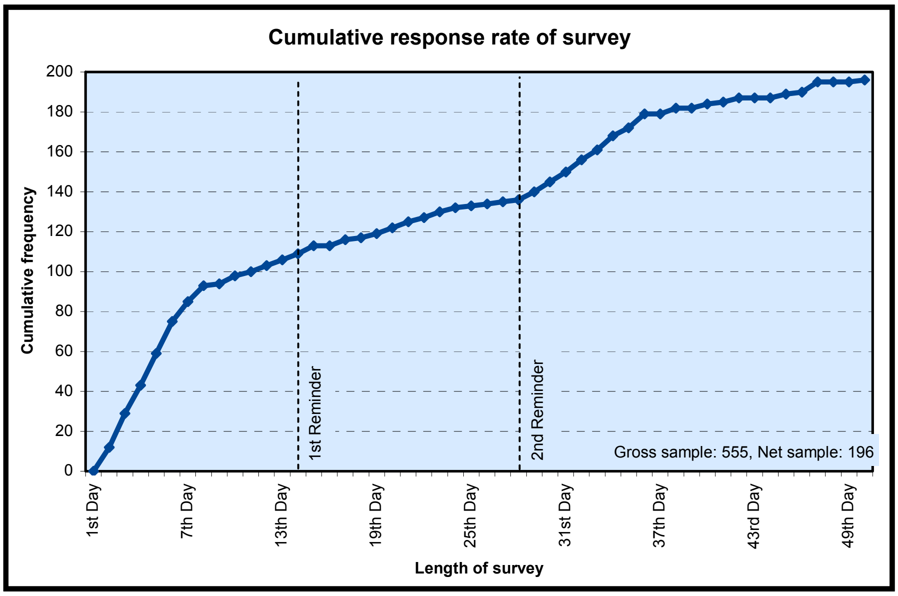

Figure 2. Cumulative rate of return

5. Results

This contribution provides some of the results of our study with the focus on the designers' degree of familiarity with disassembly-supporting connections, the degree of application and the reasons for non-consideration of these connections. Another focus is on the degree of application of conventional connections.

5.1 Analysis of frequencies

Degree of familiarity and degree of use of disassembly-supporting connections

The first important question was upon the degree of familiarity with disassembly-supporting connections, the results of which are shown in Figure 3. Not just surprisingly the *bayonet joint* is the most familiar connection. *Toggle* and *pawl latches* are also very familiar.

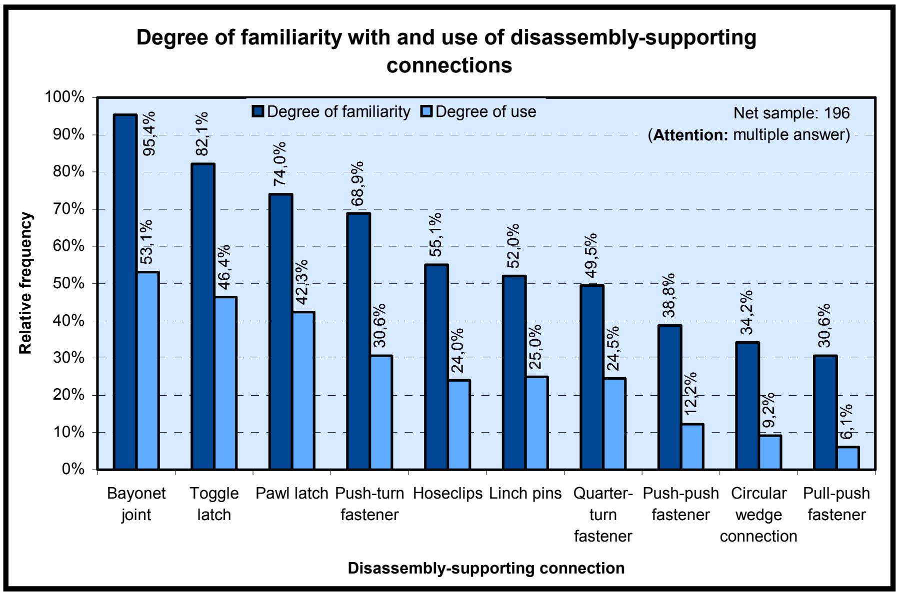

Figure 3. Degree of familiarity with and use of disassembly-supporting connections

These are the connections, whose terms are very common for a long time. Other disassembly-supporting connections are not so well-known. It has to be taken into account that the denominations for these connections are often ambiguous because there are many different embodiments of the same connection with no generally accepted but a lot of trade names. Therefore, these connections are often named according to their assembly and disassembly motions. This is one possible reason why a lot of the respondents stated that they don't know to be familiar with these connections.
Figure 3 also shows the degree of use of disassembly-supporting connections. The use of the connections seems to correlate with the designers' familiarity to them – the values of both indicators are ranked in the same order. However, the degree of use is almost only half of degree of familiarity. Approximately half of the respondents use bayonet joints for connecting parts or assemblies in their technical products; a little bit less use toggle and pawl latches. Other connections are less often used.

Degree of application of conventional connections
The degree of application of conventional connections is presented in Figure 4. It is – as expected – vast superior to the use of disassembly-supporting connections. Nearly all respondents apply connections with bolts. Welded and glued connections are also very popular: four out of five respondents apply one of these connections. More than two third trust in soldered and riveted connections. Finally, almost two third of the respondents apply snap connections within their products.

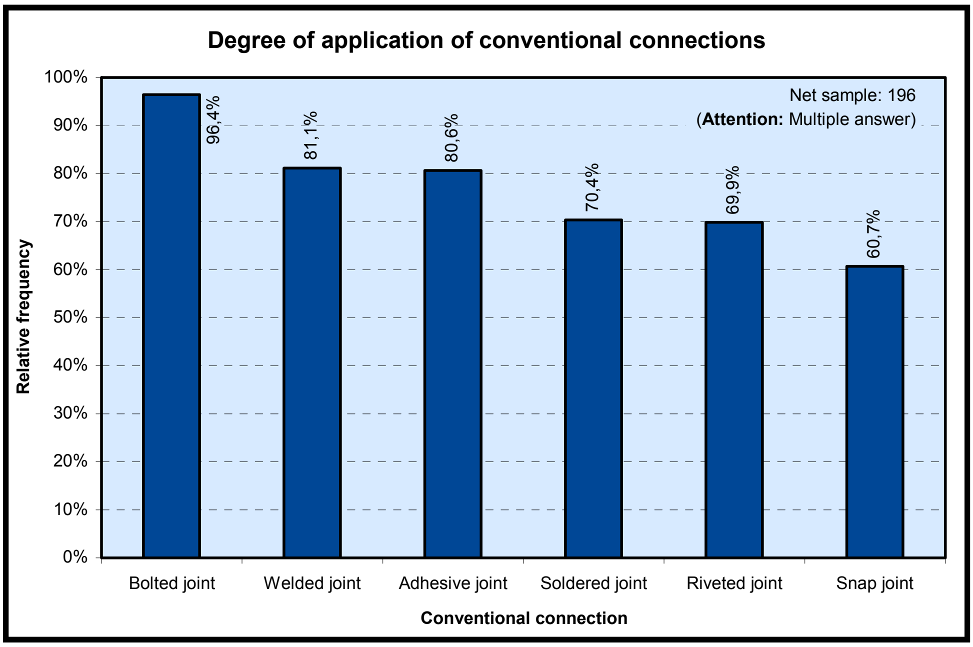

Figure 4. Degree of application of conventional connections

Reasons for non-consideration of disassembly-supporting connections
After a first evaluation, it could be realised that most of the investigated disassembly-supporting connections are little known and much less used. Figure 5 shows the reasons the respondents indicated for non-consideration of these connections. Three of four respondents indicated that they see no demand for application. More than a third is not able to use these connections because of being not familiar with them. Also more than a third stated that there is no *information* available about these connections. Information in this context is defined as data about the properties and characteristics of the considered connections. Insufficient *knowledge* is mentioned by almost a third of the respondents. Knowledge in this context comprises the experience with generally handling these connections and with the application to particular technical products. There are some other reasons for non-consideration of disassembly-supporting connections, but their proportions are low compared to the main reasons.

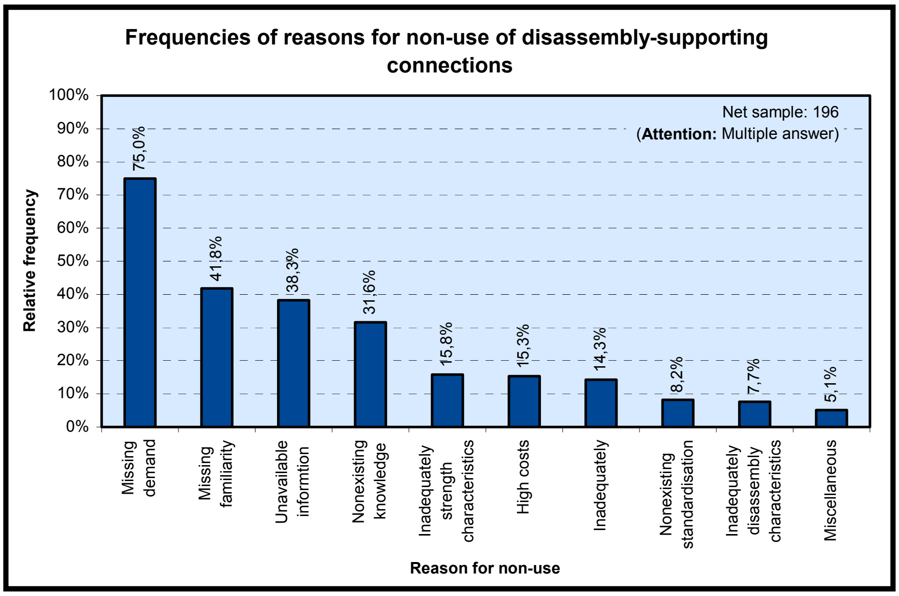

Figure 5. Reasons for non-consideration of disassembly-supporting connections

5.2 Analysis of correlations

The aim of the further statistical analysis provided here is the testing of research hypotheses by means of the collected data. The selection of the adequate statistical test is of high importance. To choose the correct test a few relevant criteria, like kind of sampling, distribution of variables, level of measurement of variables, strength and robustness of test, have to be considered [Weinbach & Grinnell 2000, p119 et seqq.]. In this study the kind of sampling was a disproportional and stratified sample, whereby the sample per stratum was drawn randomly. Because the data distribution contained no normal variables, non-parametric statistics have been applied. Thus, the χ^2-Test (chi-square) was chosen as test method. This test compares observed and expected frequencies of two variables of a so called contingency table to identify whether the observed frequencies differ significantly from the expected frequencies, thus concluding that the variables affect each other. To interpret the resulting χ^2-value, the degree of freedom has to be determined, which depends on the numbers of rows and lines of the contingency table. If the empirical χ^2-value is greater than the critical χ^2-value (taken from a table), the null hypothesis can be rejected [Bortz & Lienert 1998, p64 et seqq.].

The level of significance, i.e. the probability that a correlation arose randomly, was set to 5% ($\alpha<0{,}05$) for all tests. The tests were used to verify the expected causality between the stated main reasons and the non-consideration of disassembly-supporting connections. Therefore some comparisons were undertaken. The frequencies of the degree of use of the several connections were combined to have a general information about the whole group. For this comparison only affirmative ("yes") and negative answers ("no") were considered.

Missing of familiarity vs. degree of use of disassembly-supporting connections

Research hypothesis: If the familiarity with disassembly-supporting connections is missing then these connections are not used.

Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=14,554; df=1, p=0,000*).

Degree of familiarity with vs. degree of use of disassembly-supporting connections

Research hypothesis: If disassembly-supporting connections are not known then these connections are not used. (This comparison was undertaken to cross-check the one above.)

Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=325,634; df=1, p=0,000*).

Missing of familiarity vs. degree of familiarity with disassembly-supporting connections
Research hypothesis: If the familiarity with disassembly-supporting connections is missing then these connections are not known. (This comparison was undertaken to cross-check the statements.)
Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=18,702; df=1, p=0,000*).

Unavailability of information about vs. degree of use of disassembly-supporting connections
Research hypothesis: If information about disassembly-supporting connections is unavailable then these connections are not used.
Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=5,024; df=1, p=0,025*).

Non-existence of knowledge vs. degree of use
Research hypothesis: If knowledge about disassembly-supporting connections not exists then these connections are not used.
Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=10,175; df=1, p=0,001*).

Degree of application of conventional vs. degree of use of disassembly-supporting connections
Research hypothesis: If conventional connections are applied then disassembly-supporting connections are not used.
Result: The determined empirical χ^2-value is greater than the critical χ^2-value (χ^2=4,504; df=1, p=0,034*).

For all comparisons the null hypotheses can be rejected and the research hypotheses can be corroborated. There are correlations between the main reasons for non-consideration and the degree of use of disassembly-supporting connections. There are also correlations between the degree of familiarity with disassembly-supporting connections respectively the degree of application of conventional connections and the degree of use of disassembly-supporting connections.
The unfamiliarity with, the unavailability of information about and the non-existence of knowledge about these connections are in fact important reasons for their non-consideration; and if the respondents apply mostly conventional connections they don't consider disassembly-supporting connections.

6. Conclusion

The study described in this contribution investigated the familiarity with and the use of disassembly-supporting connections in German manufacturing industry. It could be shown that these connections are mostly unknown. This is one of the main reasons why they are not used in technical products. Other reasons are the lack of information about the characteristics and properties of disassembly-supporting connections and insufficient experience with their application. In the area of disassembly-supporting connections standardisation is almost completely absent. A comparison of similar connections of different suppliers is almost impossible if there is no information about their properties. The unmanageable variety of forms and types of disassembly-supporting connections also represents a problem for the selection of connections in practice. This is assumedly the reason why most designers use established solutions and avoid the risk of applying unknown technologies.
The study (for further details see [Wünsche 2003]) showed that there is a strong need for further research at the area of disassembly-supporting connections. Given the lack of existing information about these connections, further analytical and experimental research into the strength and disassembly characteristics of these connections is necessary. In addition this information has to be

provided to design practice effectively. In this context standards and guidelines are of particular importance. For broader use of this connections it is necessary to close the gap of information and knowledge and to develop standards to achieve a reduced connection variety. Therefore we undertake further analytical and experimental research to determine and provide the relevant information to design practice.

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