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# OPTIMIZING THE USE OF CROSS LAMINATED TIMBER IN TERMS OF THE CIRCULAR ECONOMY

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***Abstract:***
*Cross-laminated timber (CLT) can make a significant contribution to ecological change in the construction industry. In standardised CLT production, full-surface raw panels are first manufactured. To do this, laminated boards, usually made of spruce wood, are layered and glued with alternating orientations to obtain a shear-resistant solid wood material. The raw CLT panels are prepared in the work preparation stage using timber construction software with an integrated nesting application and processed into precisely cut wall, ceiling and roof elements using modern CNC technology. This scientific study confirms that around 10 per cent of the production volume is lost as waste. In order to improve resource utilisation, an adaptive production process is being researched as part of a dissertation at the University of Innsbruck. This new approach aims to significantly reduce waste, for example from window and door cut-outs or from profiles for pitched roofs.*

*In practice, this newly developed process can complement existing CLT layouts. Initial validated simulation results show that optimised nesting and segmented design can unlock greater value creation potential. By applying the new process, dismantled CLT elements could also be reused in a second phase of use in the future. The overarching goal of this research is to conserve valuable resources by making the entire production chain for CLT components more effective and sustainable. This publication first presents a statistical analysis of nesting based on key figures and diagrams. The second part provides an overview of the new process and explains the findings obtained so far.*

***Key words:*** *Cross-laminated timber, Nesting, Offcut optimization, Lean manufactoring, Circular technology.*

## INTRODUCTION

Wood is a renewable material that stores $CO_2$. This means that timber construction can be resource-efficient. The first step of this study deals with CNC waste (cuts from windows, doors, etc.) that is produced during the current standardised assembly of CLT. As things stand at present, there is no recycling process for CLT that preserves the building product or enables it to be reused at an adequate level of utilisation as wall or ceiling components. If you look at an EPD (Environmental Product Declaration) for CLT, the only recycling mentioned under the heading ‘Recycling’ is energy recycling for energy production (for heat or electricity generation). This means that cut-outs measuring several square metres are used for energy production without ever having been used.

One of the main reasons why a new approach to joinery (Re-Design) was considered and developed was to significantly reduce CNC waste and offcuts. In the Re-Design, CLT wall components are assembled segment by segment by connecting window and door lintels/parapets with full-surface wall segments. This led to a reduction in the amount of offcuts. The nesting data for this scientific study was provided by four CLT manufacturers from Austria. A total of nesting data from 79 construction projects was processed.

In the first part of the quantitative research study, the volume and surface area of CLT offcuts produced during CNC joinery are determined from the 79 construction projects in order to obtain relevant data and conclusions for a more material-efficient CLT production process.

In the second part of the scientific research, the new process of so-called Re-Design nesting is being tested by re-nesting 20 timber construction projects from a CLT manufacturer. The research is being conducted with a focus on resource-efficient circular economy and in accordance with the LEAN production system. The idea behind the LEAN production system is to avoid waste, for example in the form of overproduction or leftover pieces. The approach is that the best leftover piece is the one that is not produced in the first place. This means that overprocessing and handling are also considered wasteful. For the overview and comparison of project data, the project-related CLT quantities are classified into the categories of raw, net, offcut and recycled panels. This makes it possible to develop an interpretation and conclusion for a more resource-efficient production of CLT wall elements and to implement or find approaches for improvements.

A wood-to-wood connection in combination with load-bearing bonding of the CLT segments is used to connect the CLT segments (cut-outs/segments). A master's thesis at the Salzburg University of Applied Sciences (2022) investigated the use of general finger joints for recycling CLT for/in load-bearing wall components. The milling of 50-millimetre-long solid wood finger joints leads to additional material consumption. Therefore, in this ongoing research work, foreign springs made of wood-based materials are used instead. The shape and size of the springs are tailored to the CLT elements. The advantages of the new connection are that it requires less milling and also produces less waste. Furthermore, the springs can be arranged in such a way that the static requirements can also be optimised. One example of this is the often-problematic frame corners in a wall. This connection method can also be used when reusing CLT that has already been used once before. For the application of Re-Design nesting, the quantity/mass of the dismantled CLT walls or ceilings will be of interest in the future. This can be accompanied by resource-saving (as little to no new material is consumed) and interesting reuse in the circular economy at the same material level (no cascade use). This research is quantitative, application-oriented research in the context of industrial data science.

## OBJECTIVE

One of the main objectives of this quantitative research study is to determine/measure the volume and surface area of CLT offcuts generated during CNC joinery projects. This will enable relevant data to be obtained for further estimation of material consumption in CLT production. Furthermore, the use of CLT in terms of the circular economy is an essential part of the research. The linear resource consumption of CLT is to be minimised in connection with its manufacture. Wood, a raw material that acts as a proven CO2 store, is to be preserved and used more efficiently and sustainably as a building material in the real estate sector.

To achieve these goals, the first step was to modify the geometries of the CLT components. In the next step, the resulting nesting files, computer-aided simulation (Optipanel), CNC joinery with the Cadwork drawing programme and OriginPro software for statistical evaluation will be used. The aim is to investigate how the new process approach affects CLT waste volume. The new method, the Re-Design nesting/process, is intended to enable a more variable design of new CLT wall elements, but also of reused ones in the future. The use of dismantled CLT wall elements is another goal of this research and is mentioned in this publication but not discussed in detail.

## MATERIAL, METHOD, EQUIPMENT

Using the OrignPro Version 2025b data software, statistical series are divided into the categories of timber construction projects and material thickness. In the next step, the categories ‘raw’, “net”, ‘cut-out’ and ‘recycling’ are measured and used to determine the amount of waste in relation to the respective material cross-section of the CLT (e.g. 80, 100, 120 [mm]). The results are checked, analysed/compared and visually represented using diagrams (e.g. scatter matrix or correlogram).

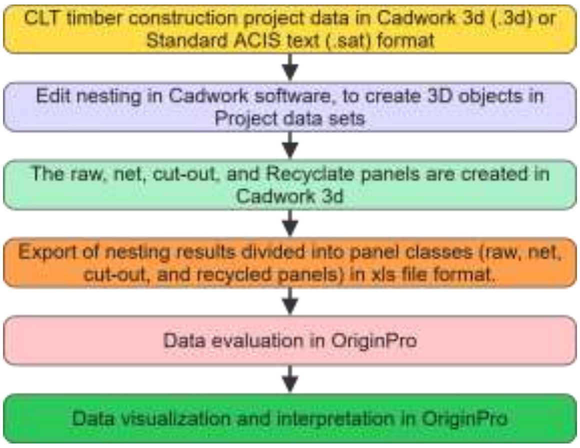


***Fig. 1.***
***Work sequence for generating and evaluating data sets.***

Data evaluation includes statistical analysis using OriginPro. The nesting results are used to obtain statistical indicators, e.g. scrap ratio and recyclate ratio, in the respective class examined (e.g. raw material, net material, scrap material and recyclate material) in the form of mean values, minimum, maximum and standard deviations for comparison.

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Vol. 21 N° 4 2025
pp. 15-24

The 79 nesting files used in this study comprised 3,572 raw panels with a total area of 92,98 [m²] and a total volume of 13,26 [m³]. All nesting files originate from the industry of research partners of Austrian CLT manufacturers. Specifically, A=20; B=20; C=19; D=20 timber construction projects per source (CLT manufacturer) were used for the evaluation. The evaluation method used in this study is based on the application of the nesting module (OptiPanel Version v.2 12 31) integrated into the CAD software (Cadwork Version 2025). Nesting is an optimisation process used in the work preparation of cross-laminated timber (CLT). More precisely, special software such as OptiPanel from Cadwork 'nests' the various CLT component geometries. This means that it arranges the individual elements on the large CLT raw panel in such a way that as little offcuts as possible are produced. The software digitally rotates and shifts the components (depending on the orientation of the respective top layer and the material thickness) in order to nest/arrange them optimally. The aim of nesting is to minimise offcuts and thus material costs. In addition, processing times can be optimised with the associated tool changes in joinery. Relevant data sets are read from nesting structures and listed in classes.

The CLT raw panels, CLT wood components, CLT cut-outs resulting from CNC joinery and CLT recyclates are thus generated digitally or further processed in Cadwork or hsbcad. The output of results, which enables a detailed parts list output via a list module in Cadwork, allows the use of CLT recyclates in the area = A [m²] and volume = V [m³] as/in XLS files for further statistical evaluation (descriptive statistics for waste analysis). OriginPro Version 2025b software is used for statistical evaluation and visualisation of the results.

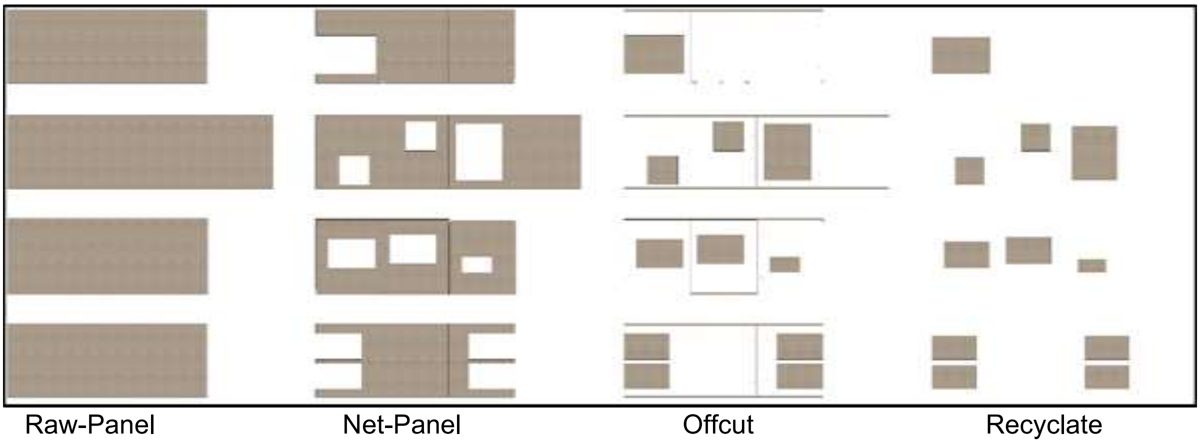



***Fig. 2.***
***Manufacturing of Wall elements made of Cross-Laminated Timber with Standard nesting (example:1).***

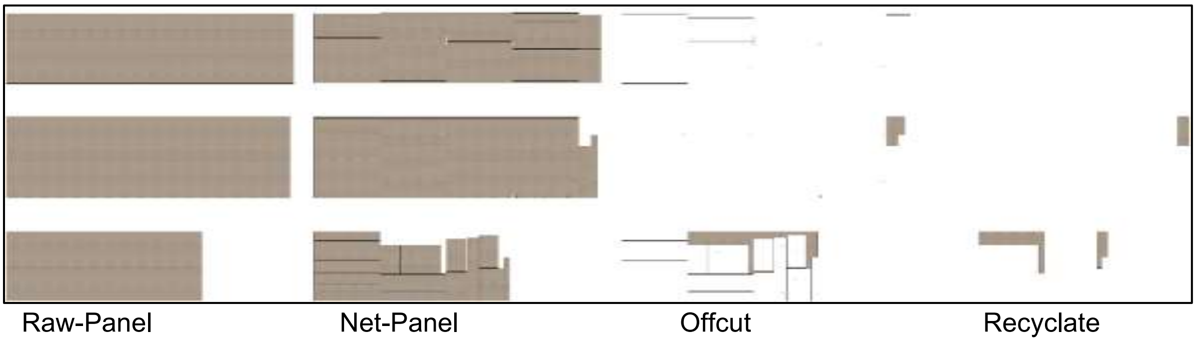
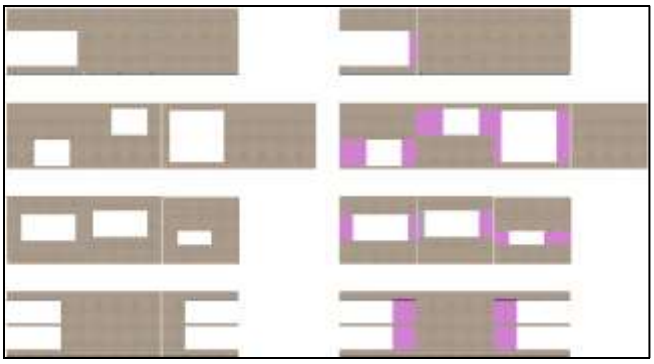



***Fig. 3.***
***Manufacturing of Wall elements made of Cross-Laminated Timber with Re-Design nesting (example:1).***



Net-Panel by Standard nesting I Net-Panel by Re-Design nesting

***Fig. 4.***
***CNC joinery results: Standard nesting vs. Re-Design nesting (example:1).***

The production of wall elements from CLT with standard nesting is mainly used in industrial prefabrication (work preparation). (Fig. 2) In this nesting process, raw panels are covered with wall or ceiling components and processed using CNC technology. In the new nesting process called Re-Design nesting, the raw panels are covered with segmented wall components and combined with each other. The segmented wall components are digitally assembled into complete wall elements. (See Fig. 4 Purple door/window lintels and parapets) By applying the Re-Design nesting process, there is hardly any waste in the form of cut-outs. (Tab.1)

*Table 1*

***Standard nesting (1) and Re-Design nesting (2) Numerical***
***(this partial values are taken from a involved CLT project.) (Projektbeispiel: x1)***

| **(1) Raw Panels** | **(1) Net Panels** | **(1) Offcuts** | **(1) Recyclate** | **(1) Final Panels** |
|---|---|---|---|---|
| A = 124,76 m² | A = 95,31 m² | A = 33,22 m² | A = 25,94 m² | A = 95,31 m² |
| (100%) | (81,28%) | (20,61%) | (16,02%) | |
| V = 17,48 m³ | V = 13,24 m³ | V = 4,23 m³ | V = 3,63 m³ | V = 13,24 m³ |
| (100%) | (81,30%) | (15,90%) | (13,33%) | |
| **(2) Raw Panels** | **(2) Net Panels** | **(2) Offcuts** | **(2) Recyclate** | **(2) Final Panels** |
| A = 99,91 m² | A = 95,31 m² | A = 4,61 m² | A = 3,10 m² | A = 95,31 m² |
| (100%) | (95,54%) | (4,61%) | (3.10%) | |
| V = 13,99 m³ | V = 13,34 m³ | V = 0,65 m³ | V = 0,43 m³ | V = 13,24 m³ |
| (100%) | (94,63%) | (4,62%) | (3,10%) | |

Table 1 uses an example to illustrate the differences in the results of the two nesting methods used in this scientific paper (see the third column: Offcuts). Part (1) of the table shows the results from Fig. 2 Manufacturing of wall elements made of CLT with standard nesting in key figures. Part (2) of Table 1 shows the results from Fig. 3 Manufacturing of wall elements made of CLT with Re-Design nesting broken down.
Fig. 4 shows the results for the net panel. The results of Standard nesting are shown on the left-hand side and the results of Re-Design nesting on the right-hand side. The segments shown in purple indicate the joined window and door lintels and window parapets.
Another ongoing research project at the Timber Construction Department of the University of Innsbruck is investigating the possibilities of joining CLT segments together. The focus here is on a mechanically stable wood-wood connection, which is to be additionally reinforced with a load-bearing adhesive (1-component polyurethane). The starting point for this research is general finger jointing with a finger length of up to 50 millimetres (Fig. 5).

***Fig. 5.***
***Example: Wood connection for Cross-Laminated Timber with Re-Design***
**left: joint with spring clip, right: assembled wall element.**

By using a joining method that consists of 99 per cent wood and 1 per cent adhesive, it is possible to segment the components obtained from dismantling. In a further process step, new components can be manufactured through sorting and the Re-Design nesting process. With this joining method, the aforementioned foreign spring can be incorporated to create a corresponding form-fitting or force-fitting connection between the CLT segments. Depending on the stress and use, the foreign springs can be made from wood-based materials with better mechanical properties, such as laminated veneer lumber, construction beech, plywood, etc.

**Blend and recycled content**

The proportion of waste and recycled material was determined for each CLT project. The key figures are the volume [m³] and area [m²] of the waste. The areas are used for comparison purposes only, to illustrate the associated deviation from the volume. Volume is the relevant variable or unit, as it is the more suitable indicator for different panel cross-sections (thicknesses) when establishing a reference to raw material consumption, for example. The proportion of waste and recycled material refers to the project-related quantity of raw panels and is expressed as the waste volume in percent (waste vol. %). To statistically substantiate this fact (volume to area), this difference can be demonstrated using the key figures (see Table 3 Results of the statistical analysis of four different sources: Standard nesting waste (1) ). In addition to the recycled volume [%], the recycled area [%] was also determined. In the production of CLT raw panels, there are differences in the formats that can be produced [length and width]. For the study conducted here, the nestings of producer B were used with the Re-Design nestings. The aim is to compare the differences in terms of material consumption. The following table shows the CLT formats that can be produced by the four CLT manufacturers.

*Table 2*

**Information from the respective declarations of performance (DoP) of the Cross-Laminated Timber Producers**

| Producer | Cross-Section | Width | Width-Grid | Length | Length-Grid |
|---|---|---|---|---|---|
| ***CLT-1*** | 60 bis 360 | 1.300 | | | +/-100 |
| | | min. 2.250 | +/- 200 | min. 8.000 | |
| | | max. 2.950 | | max. 16.000 | |
| | | 3.250; 3.450 | | | |
| ***CLT-2*** | 60 bis 320 | min. 2.450 | +/- 50 | min. 8.000 | +/- 10 |
| | | max. 3.100 | | max. 14.500 | |
| ***CLT-3*** | 51 bis 315 | min. 2.400 | | min. 5.000 | |
| | | max. 3.500 | | max. 22.000 | |
| | | 2.400; 2.600; 2.750; 2.950; 3.020; 3.500; | | | |
| ***CLT-4*** | 51 bis 350 | 1.250 | | min. 5.000 | |
| | | | | max. 24.000 | |

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www.proligno.ro
Vol. 21 N° 4 2025
pp. 15-24

## RESULTS AND DISCUSSION

### Cut analysis Standard nesting sections

As already mentioned, the results of this study are based on the analysis of 79 projects from four CLT manufacturers. The results in Table 2 show that the average amount of waste generated by CNC cutting is 10.94%. Depending on the project, there is a range of variation from a minimum of 1.39% to a maximum of 36.86%. The figures refer to the raw panel volume [m³] specified in column 2 of Table 2. Figure 6 provides an overview of the raw panel cross-sections used in the 79 CLT projects, showing the most frequently used cross-sections. In summary, the four most common cross-sections are: 100 [mm] (16.08%), 160 [mm] (15.65%), 200 [mm] (15.44%) and 140 [mm] (14.81%), which together account for 61.98%.

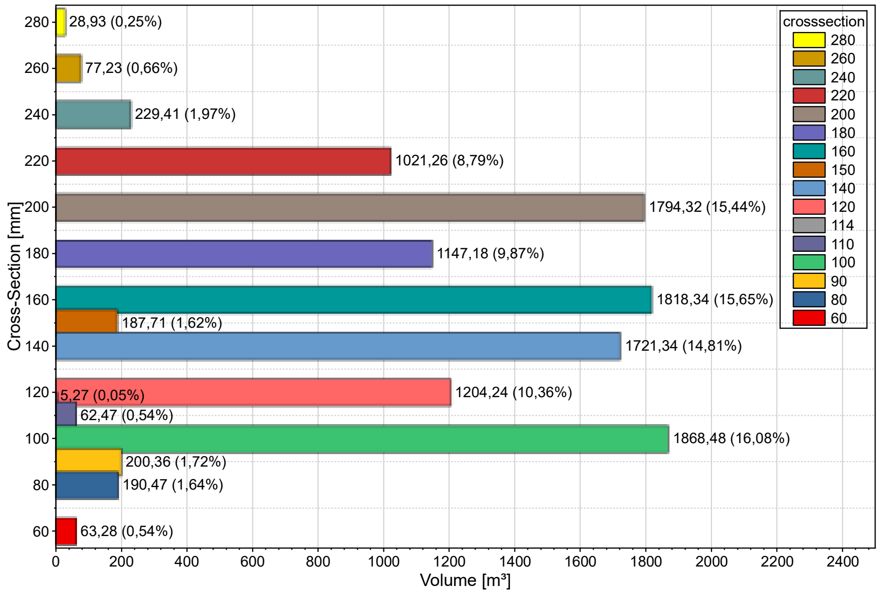


***Fig. 6.***
***Evaluation of raw-panels by 79 CLT Projects from 4 Producers by volume [m³].***

Figure 7 shows how much recycled material from offcuts in cross-sections was produced by CNC milling in the 79 CLT projects. The four most common cross-sections are summarised as follows: 100 [mm] (20.08%), 140 [mm] (17.30%), 160 [mm] (14.98%) and 120 [mm] (14.10%). These four cross-sections together account for 66.45% of the total.

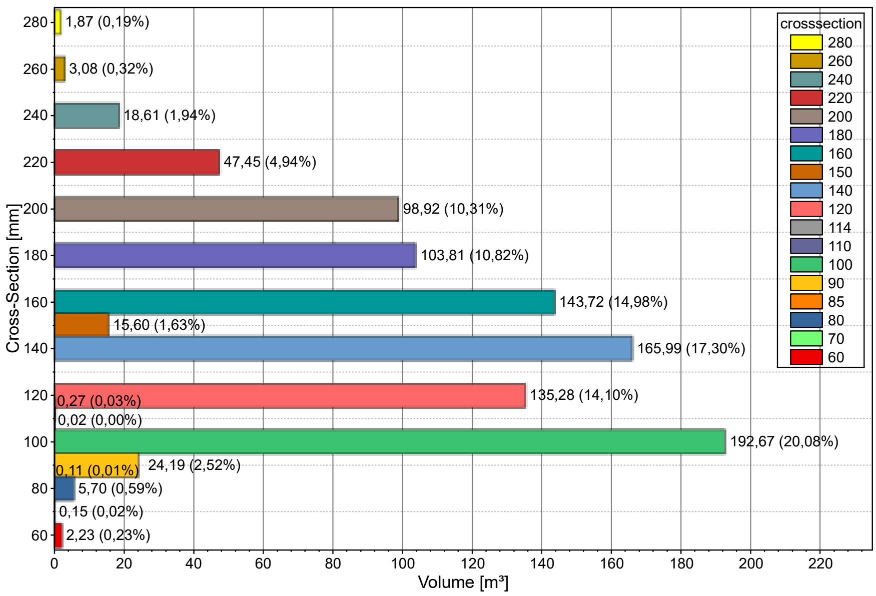


***Fig. 7.***
***Evaluation of* recycl*ate by 79 CLT Projects from 4 Producers by volume [m³].***

Figure 8: Evaluation of recyclate by 79 CLT projects from 4 producers in width [m] vs length [m] by fraction uses a scatter diagram and percentage distribution to illustrate the recyclates produced. The length of

ONLINE ISSN 2069-7430 ISSN-L 1841-4737 | PRO LIGNO www.proligno.ro | Vol. 21 N° 4 2025 pp. 15-24

the CLT elements is shown on the Y-axis and the width on the X-axis. 67.33% of the recyclate occurs within the length interval 0.20 to 2.00 [m] and 60.73% within the width interval 0.20 to 1.25 [m]. The orientation of the cover layers is of secondary importance, as this study considers the dimensions of the recycled materials produced during CNC joinery or Standard nesting.

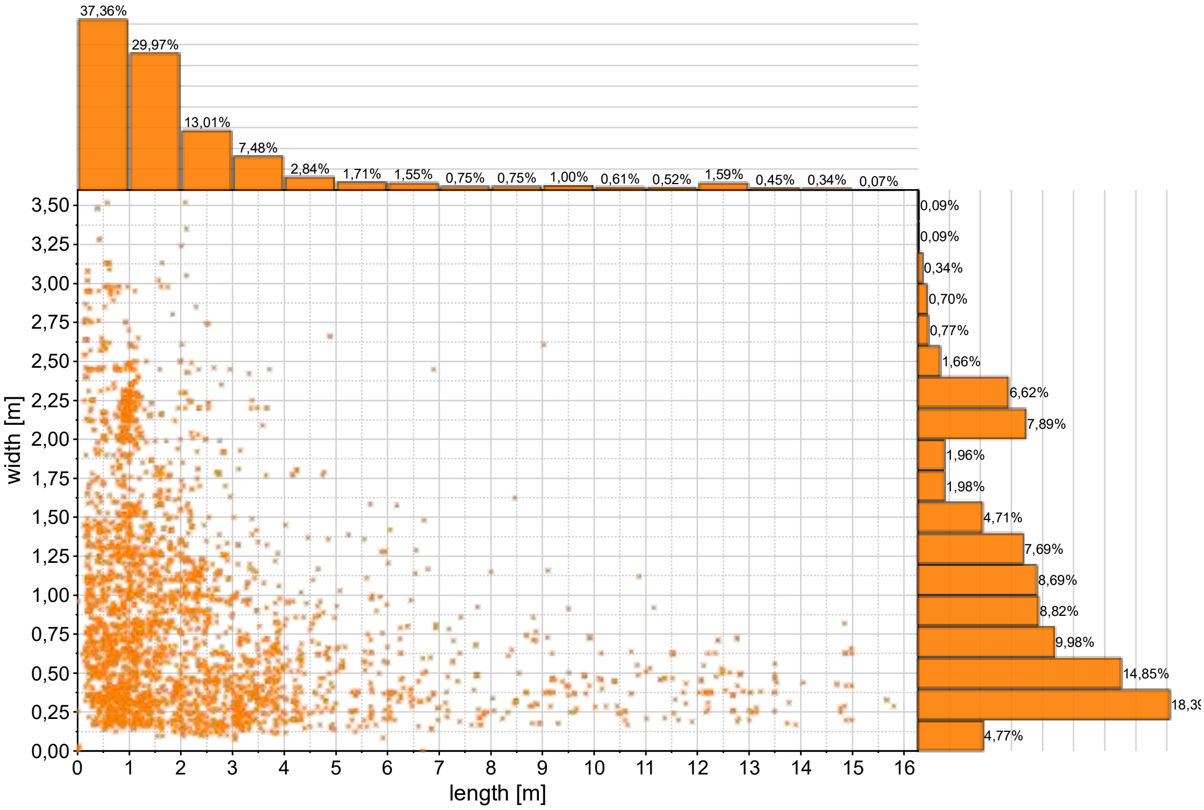


***Fig. 8.***
***Evaluation of* recyclate by 79 CLT Projects from 4 Producers in width[m] vs length[m] by fraction.**

To gain a detailed insight into the evaluation of the four different CLT manufacturers, Table 3 shows the broken-down statistics sorted into columns. The differences in waste and recycled material volumes that arise at the respective CLT manufacturers are shown in units of volume [m³] and as a percentage. As additional information, the last two columns show the area of the recyclates as a percentage with the volume as a percentage. The area tends to be larger than the volume, which can be explained by the different cross-sections.

*Table 3*

***Results of statistical analysis of four different souces: Standard nesting offcuts***

| A (n = 20)<br>B (n = 20)<br>C (n = 19)<br>D (n = 20) | Raw Vol. [m³] | Net Vol. [m³] | Offcut Vol. [m³] | Offcut Vol. [%] | Recyclate Vol. [m³] | CLT Pieces | Gross Recyclate Area [%] | Gross Recyclate Vol. [%] |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| Total | 2.592,91 | 2.331,77 | 259,17 | | 165,42 | 1.224 | | |
| Mean | 129,65 | 116,59 | 12,96 | 9,91% | 8,27 | 61,20 | 7,08% | 6,29% |
| Min | 96,85 | 95,01 | 1,84 | 1,39% | 0 | 0 | 0% | 0% |
| Max | 150,19 | 137,91 | 18,86 | 14,97% | 12,92 | 109 | 11,81% | 9,95% |
| SD | 11,05 | 9,98 | 5,19 | | 4,15 | 31,07 | | |
| | | | | | | | | |
| Total | 4.848,64 | 4.313,61 | 532,58 | | 423,38 | 1.847 | | |
| Mean | 242,43 | 215,68 | 26,63 | 11,33% | 21,17 | 92 | 9,22% | 8,98% |

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Vol. 21 N° 4 2025
pp. 15-24

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|---|---|---|---|---|---|---|---|---|
| Min | 53,08 | 46,37 | 5,51 | 7,83% | 4,98 | 30 | 5,10% | 5,47% |
| Max | 903,04 | 831,23 | 71,98 | 16,20% | 60,38 | 233 | 14,49% | 14,30% |
| SD | 224,59 | 203,15 | 23,01 | | 18,53 | 63,53 | | |
| | | | | | | | | |
| Total | 4.302,40 | 3.888,82 | 413,44 | | 278,89 | 1240 | | |
| Mean | 226,44 | 204,67 | 21,76 | 12,86% | 14,68 | 65,26 | 9,48% | 9,50% |
| Min | 7,25 | 5,73 | 1,44 | 5,22% | 0,99 | 4 | 2,44% | 2,23% |
| Max | 670,54 | 635,37 | 56,63 | 29,13% | 40,50 | 328 | 24,09% | 25,49% |
| SD | 191,70 | 176,19 | 18,27 | | 12,86 | 77,23 | | |
| | | | | | | | | |
| Total | 1.508,50 | 1.373,95 | 136,91 | | 94,36 | 262 | | |
| Mean | 75,43 | 68,70 | 6,85 | 9,75% | 4,72 | 13,10 | 6,61% | 6,58% |
| Min | 3,36 | 2,12 | 0,40 | 1,52% | 0 | 0 | 0% | 0% |
| Max | 659,65 | 588,54 | 73,48 | 36,86% | 56,65 | 96 | 35,42% | 35,44% |
| SD | 163,50 | 147,78 | 16,59 | | 12,44 | 22,63 | | |
| | | | | | | | | |
| **Total** | 13.252,48 | 11.908,15 | 1.342,09 | | 962,05 | 4.573 | | |
| **Mean** | 167,75 | 150,74 | 16,99 | **10,94%** | 12,18 **(71,69%)** | 57,89 | **8,08%** | **7,82%** |
| **Min** | 3,36 | 2,12 | 0,40 | 1,39% | 0 | 0 | 0% | 0% |
| **Max** | 903,04 | 831,23 | 73,48 | 36,86% | 60,38 | 328 | 35,42% | 35,44% |
| **SD** | 180,37 | 163,43 | 18,52 | | 14,34 | 59,93 | | |

In summary, the average value of the waste material in terms of volume is 10.94%. The average value of the recycled material in terms of area is 8.08% and in terms of volume is 7.82%. These values are related to the quantity of raw panels in volume [m³] in the first column (the listing of the column with the produced raw panel surface area has been omitted here). Figure 9 below shows the results broken down in more detail for the four CLT manufacturers. The cutting waste volume ranges from 9.08% for manufacturer (D) to 10.98% for manufacturer (B). The analyses revealed a recycling rate of at least 6.26% for manufacturer (D) and a maximum of 8.73% for manufacturer (B).

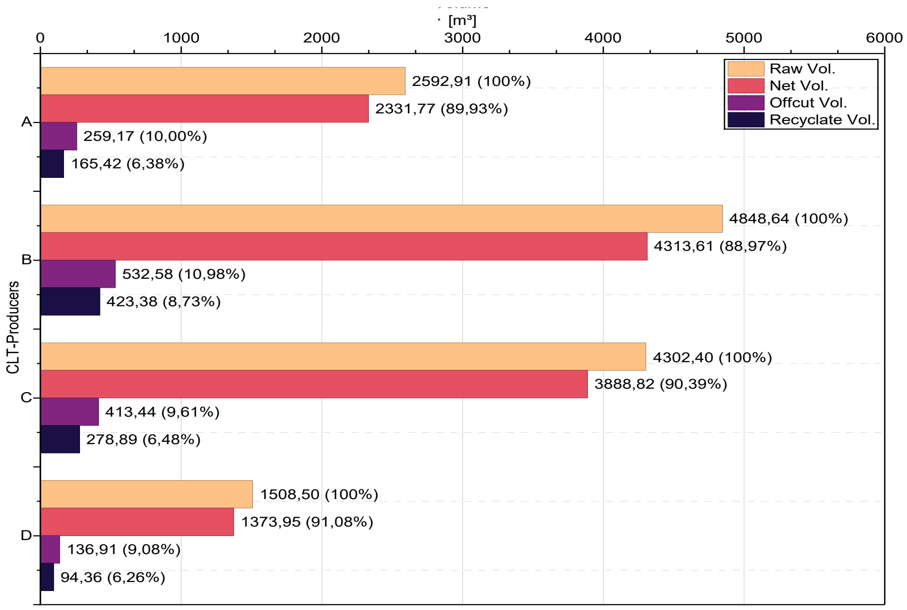


***Fig. 9.***
***Results of the evaluation of the four CLT Producers with 79 Projects.***

**Cut analysis Redesign Nesting**

In this section, 20 timber construction projects from manufacturer B are used to compare the new nesting process. To do this, the project files were prepared so that window and door cut-outs were no longer created where possible. The main aim of the new nesting process is to reduce material waste.

The results table is structured so that the columns with comparable data between Standard nesting and Re-Design nesting are arranged side by side. In detail, the values for Re-Design nesting show that improved results were achieved in the categories of raw panels and waste. For raw panels, the difference is minus 117.93 m³ (-2.43%) compared to Standard nesting. For offcuts, there is a reduction of 118.37 m³ (-22.23%). For recyclate, there is a reduction of 150.84 m³ (-35.63%). In theory, recycled material (less offcuts = recycled material) should be viewed positively if its use can achieve an economic advantage through opportunity costs. It is important to note that the results in the net panels category remain unchanged, as the component volume remains constant.

The construction projects BP:10 and BP:15 are special cases, as they were not processed with Re-Design nesting because there are no relevant door or window openings in these projects. According to the manufacturer's specifications, two construction projects, BP:09 and BP:17, were produced several times. These were therefore included in the results tables according to the respective production numbers (2*BP:09 and 3*BP:17).

*Table 4*

***Results of statistical analysis of Standard nesting (CLT) and Re-Design nesting (Re-CLT) with data of Producer B***

| | CLT raw | Re-CLT raw | CLT net | Re-CLT net | CLT cutoff | Re-CLT cutoff | CLT Rezyclat | Re-CLT Rezyclat |
|---|---|---|---|---|---|---|---|---|
| BP:01 | 307,51 | 287,69 | 278,75 | 278,75 | 28,76 | 8,94 | 25,61 | 4,73 |
| BP:02 | 85,24 | 78,71 | 76,40 | 76,40 | 8,70 | 2,32 | 8,38 | 1,44 |
| BP:03 | 123,95 | 123,82 | 110,23 | 110,39 | 13,72 | 13,43 | 7,61 | 6,91 |
| BP:04 | 172,65 | 165,59 | 155,00 | 154,93 | 15,62 | 8,62 | 9,59 | 2,84 |
| BP:05 | 128,20 | 121,88 | 110,36 | 110,36 | 17,84 | 12,17 | 15,72 | 7,37 |
| BP:06 | 137,59 | 134,39 | 126,54 | 126,54 | 11,11 | 7,85 | 7,52 | 2,01 |
| BP:07 | 92,15 | 88,89 | 83,53 | 83,56 | 8,63 | 5,33 | 6,48 | 3,21 |
| BP:08 | 61,37 | 58,47 | 55,86 | 55,85 | 5,51 | 2,62 | 4,98 | 1,71 |
| BP:09 | 53,08 | 49,11 | 46,37 | 46,37 | 6,71 | 2,74 | 5,19 | 1,37 |
| BP:09 | 53,08 | 49,11 | 46,37 | 46,37 | 6,71 | 2,74 | 5,19 | 1,37 |
| BP:10 | 515,43 | 515,43 | 450,22 | 450,22 | 65,21 | 65,21 | 52,41 | 52,41 |
| BP:11 | 91,61 | 88,18 | 81,66 | 81,66 | 9,95 | 6,52 | 8,55 | 3,94 |
| BP:12 | 78,35 | 72,35 | 65,66 | 65,66 | 12,69 | 6,69 | 11,20 | 4,80 |
| BP:13 | 132,42 | 134,45 | 115,16 | 115,78 | 17,25 | 18,60 | 13,52 | 12,55 |
| BP:14 | 482,33 | 482,33 | 439,52 | 439,52 | 42,81 | 42,81 | 38,17 | 38,17 |
| BP:15 | 118,80 | 117,71 | 104,77 | 104,77 | 14,03 | 12,95 | 10,44 | 7,55 |
| BP:16 | 903,04 | 886,86 | 831,23 | 831,30 | 71,98 | 55,56 | 60,38 | 27,39 |
| BP:17 | 437,28 | 425,24 | 378,66 | 378,69 | 58,44 | 46,37 | 44,15 | 30,91 |
| BV:17 | 437,28 | 425,24 | 378,66 | 378,69 | 58,44 | 46,37 | 44,15 | 30,91 |
| BP:17 | 437,28 | 425,24 | 378,66 | 378,69 | 58,44 | 46,37 | 44,15 | 30,91 |
| **Total** | 4.848,64 | 4.730,71 | 4.313,61 | 4.314,51 | 532,58 | 414,21 | 423,38 | 272,53 |
| **Mean** | 242,43 | 236,54 | 215,68 | 215,73 | 26,63 | 20,71 | 21,17 | 13,63 |
| **Min** | 53,08 | 49,11 | 46,37 | 46,37 | 5,51 | 2,32 | 4,98 | 1,37 |
| **Max** | 903,04 | 886,86 | 831,23 | 831,30 | 71,98 | 65,21 | 60,38 | 52,41 |
| **SD** | 224,59 | 221,72 | 203,15 | 203,14 | 23,01 | 20,83 | 18,53 | 15,42 |

## CONCLUSIONS

The results from standard nesting have shown that 79 timber construction projects examined produced 10.94% waste. Up to 71.69% of this waste can be recycled. Interdisciplinary collaboration, i.e. no silo thinking, in the development and optimisation of new solutions would be helpful and effective in reducing waste and ensuring that high-quality cross-laminated timber is not wasted.

The results with the new Re-Design nesting system show improved material utilisation, which can be quantified by the reduction in waste from 532.58 m³ to 414.21 m³. In summary, it can be said that the application of the new Re-Design nesting process allows for the production of material-saving CLT elements. Considerations based on the lean production approach show that the best waste is no waste at all. This is because overproduction can be considered wasteful. The new Re-Design solution enables wood to be used in a more resource-efficient and sustainable manner.

The initial research results on the connection with an external spring for assembling the CLT segments with the system: external spring made of wood-based materials, show positive results and are being further investigated. Based on the findings obtained in this work and the laboratory tests and results currently in progress, there is a tendency towards the possibility of embedding used CLT segments for reuse in a recycling process in the future.

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