19.06.2025

Parameters & Sub-Parameters

Parameters	Sub-Parameters
3.06 | Ease of Disassembly	0.22 | Setup Time
	0.50 | Skill Level
	0.28 | Portability
3.68 | Design Documentation	
2.65 | Damage Probability	0.28 | Minor Damage Probability
	0.52 | Major Damage Probability
	0.20 | Precision
1.50 | Accessibility of Connection	
2.40 | End of Cycle Waste	
2.70 | Ease of Reassembly	0.22 | Setup Time
	0.50 | Skill Level
	0.28 | Portability
1.26 | Prefabrication Degree	
1.49 | Tolerance	
2.41 | Number of Steps and Time	0.50 | Number of Steps
	0.50 | Time
1.06 | Size	
1.00 | Structural Strength	
2.80 | Connection Complexity	0.10 | Connection Type
	0.30 | Industry Preference
	0.30 | Specialized Tools
	0.30 | Time

Figure 1: Hierarchical structure of parameters and sub-parameters for reusability assessment

Definitions and Scoring

1. End of Cycle Waste

This parameter assesses the amount of material that can be reused when the connection system is disassembled. It is assessed comparatively by identifying the non-reusable components of both processes. The ratio of these components to the initial materials measures end-of-cycle waste. For Design for Disassembly (DfD) connections, this ratio equals one. It also takes into account the cement type and concrete class

$$\text{End of Cycle Waste Score} = \frac{\text{Reuasable Area}}{\text{Joint Area}} \times \frac{1}{RF_{\text{material}}} \tag{1}$$

where RF_{material} is the reduction factor for different materials:

- RF_{mortar} = reduction factor for mortar.Please see table 1.
- $RF_{\text{reinforcement}}$ = reduction factor for reinforcement.Please see table 1.

Definition of the joint area is given below.

- Column-Column Connection
- Wall-Wall Horizontal Connection
  The joint area for horizontal wall connections is calculated as:
  $$\text{Joint Area} = \text{length} \times \text{width} \tag{2}$$
- **Other Connections**
  For other types of connections, the joint is calculated as:
  $$\text{Joint} = \min(\text{length}, \text{width}) \times \text{height} \tag{3}$$

Table 1: Reduction Ratios and End-of-Cycle Waste for Mortar Types

Strength Class	Mortar Type	Reduction Ratio
C12/15	IIIA	2.03
	IIIB	2.29
	IIIC	2.50
	I	1.82
C20/25	IIIA	1.98
	IIIB	2.23
	IIIC	2.44
	I	1.69
C30/37	IIIA	1.85
	IIIB	2.09
	IIIC	2.30
	I	1.57
C40/50	IIIA	1.74
	IIIB	1.96
	I	1.46
C45/55	IIIA	1.70
	IIIB	1.90
	IIIC	2.10
	I	1.44
C50/60	IIIA	1.53
	IIIB	1.75
	I	1.28
C55/67	IIIA	1.58
	IIIB	1.60
	I	1.38
C60/76	IIIA	1.52
	IIIB	1.64
	I	1.29
C70/85	IIIA	1.27
	IIIB	1.37
	I	1.10
C80/95	IIIA	1.15
	IIIB	1.08
	I	1.04
C90/105	IIIA	1.08
	IIIB	1.04
	I	1.04
Reinforcement		0.21

2. Damage Probability

This assesses the probability of damaging connection components or adjacent elements during disassembly and reassembly, as well as the precision of the tools. It will be combined with tool time.

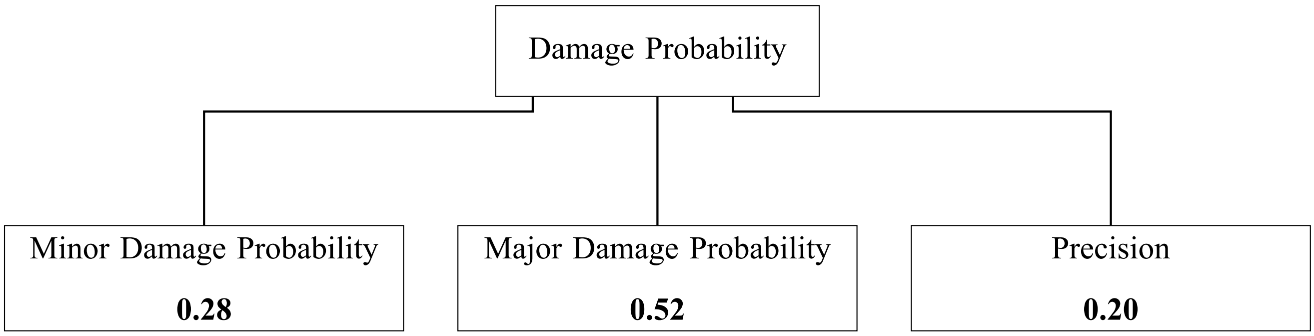

Figure 2: Damage Probability Components and Weight Factors

Minor Damage Probability

It classifies the tools based on their vibration value and linked with minor damage probability.

Table 2: Minor Damage Probability Scoring System

Damage Level	**Probability Score**	**λ (per minute)**
Low	0.2	0.0074
Moderate	0.4	0.0170
High	0.6	0.0305
Very High	0.8	0.0536

The Minor Damage Probability is calculated using:

$$P(t) = 1 - e^{-\lambda t} \tag{4}$$

$$P_{\text{score}} = \prod_{i=1}^{n} (1 - p_i) \tag{5}$$

where $t = 30$ minutes for the values shown in the table.

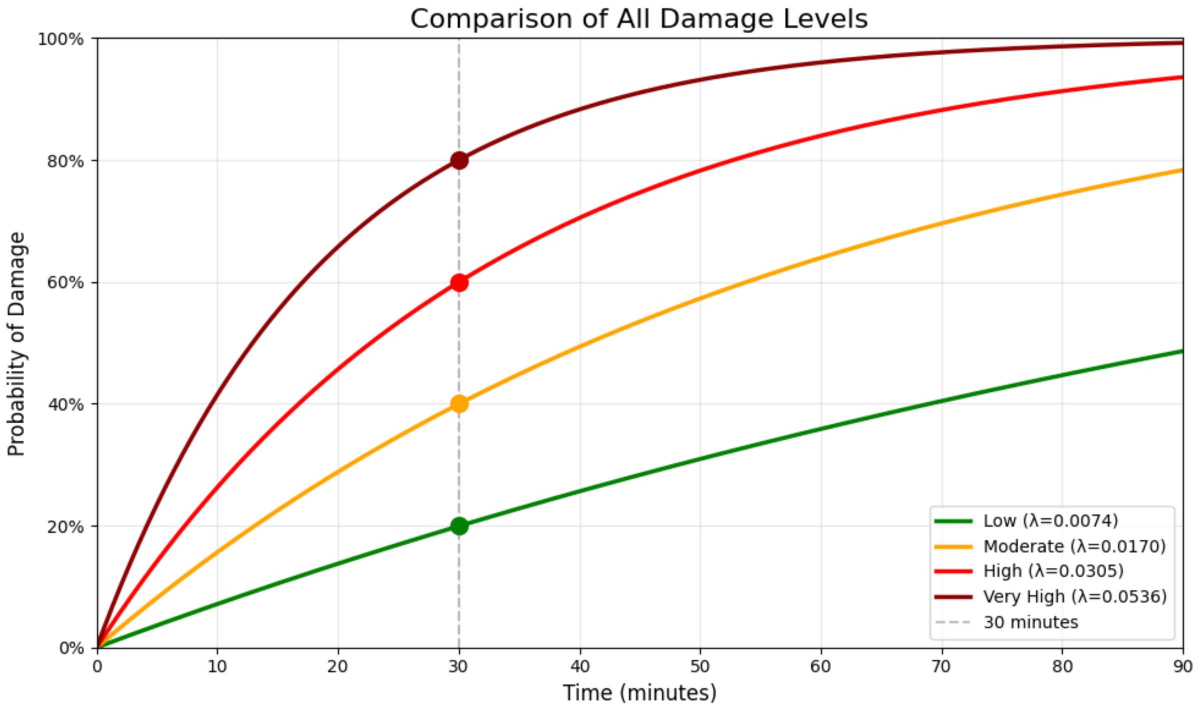

Figure 3: Minor Damage Probability Visualization

Major Damage Probability

This type of damage cannot be easily repaired; additional measurements must be taken.

Table 3: Major Damage Probability Scoring System

Damage Level	**Probability Score**	**λ (per minute)**
Low	0.1	0.0035
Moderate	0.2	0.0074
High	0.3	0.0119

The Major Damage Probability is calculated using:

$$P(t) = 1 - e^{-\lambda t} \tag{6}$$

$$P_{\text{score}} = \prod_{i=1}^{n} (1 - p_i) \tag{7}$$

where $t = 30$ minutes for the values shown in the table.

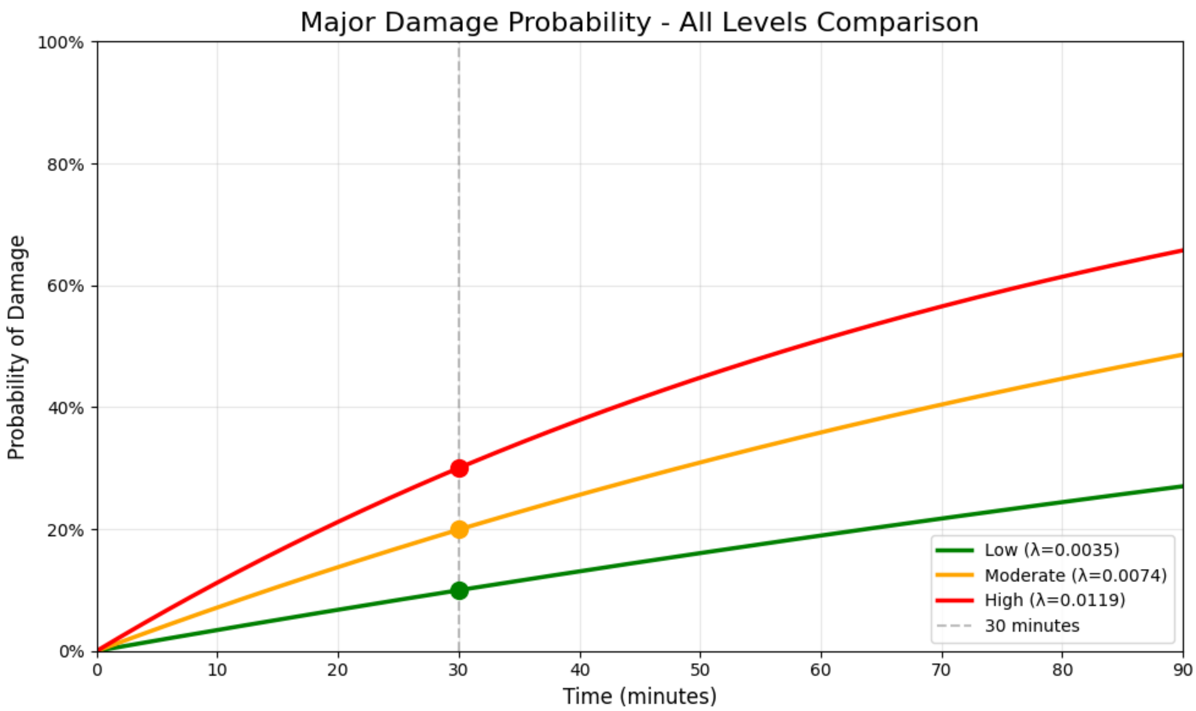

Figure 4: Major Damage Probability Visualization

Precision

This sub-parameter indicates the precision of the tools used.

Table 4: Precision Scoring System

Precision Level	Probability Score	λ (per minute)
High	0.9	0.0035
Moderate	0.6	0.0170
Low	0.3	0.0402

The Precision is calculated using:

$$P(t) = e^{-\lambda t} \tag{8}$$

$$P_{\text{score}} = \prod_{i=1}^{n} p_i \tag{9}$$

where $t = 30$ minutes for the values shown in the table.

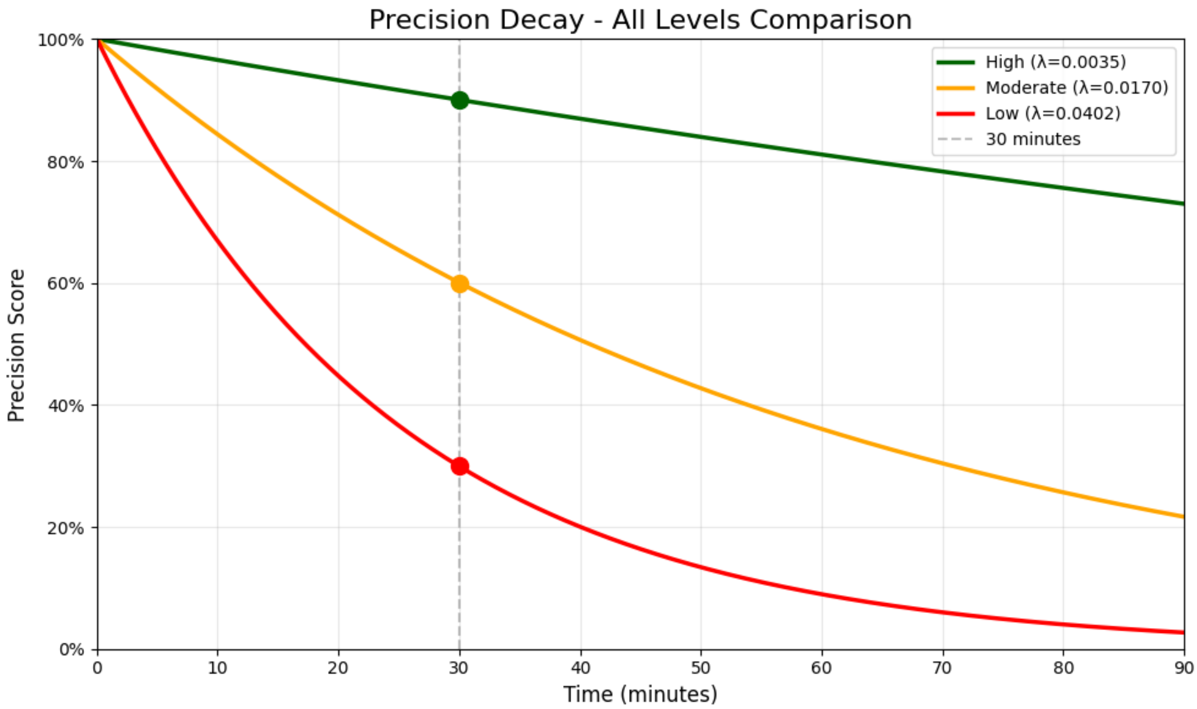

Figure 5: Precision Visualization

3. Ease of Disassembly

This parameter quantifies all procedures required to disassemble the connection system, encompassing the necessary tools, required labor skill level, and setup time as shown below. The assessment is divided into two categories: when no connectors are included, three subparameters are evaluated; otherwise, the number of connectors is incorporated as an additional parameter.

Connections without Connectors:

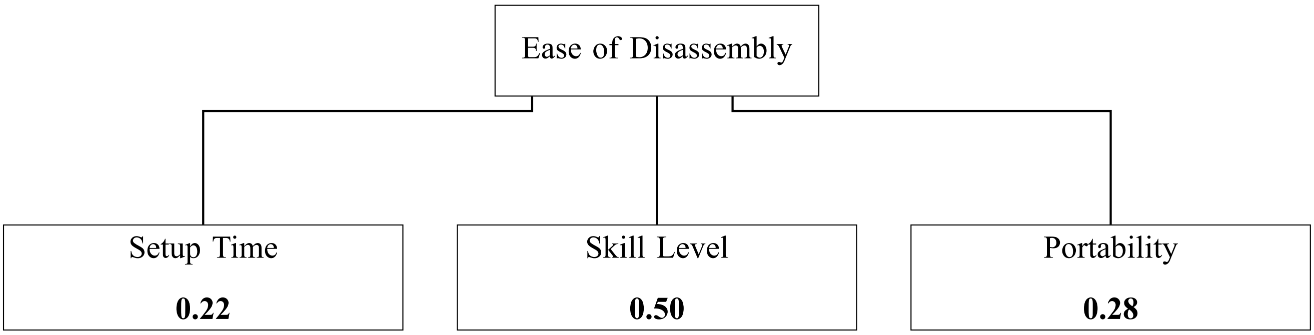

Figure 6: Ease of Disassembly Sub-parameters and Weight Factors

Connections with Connectors:

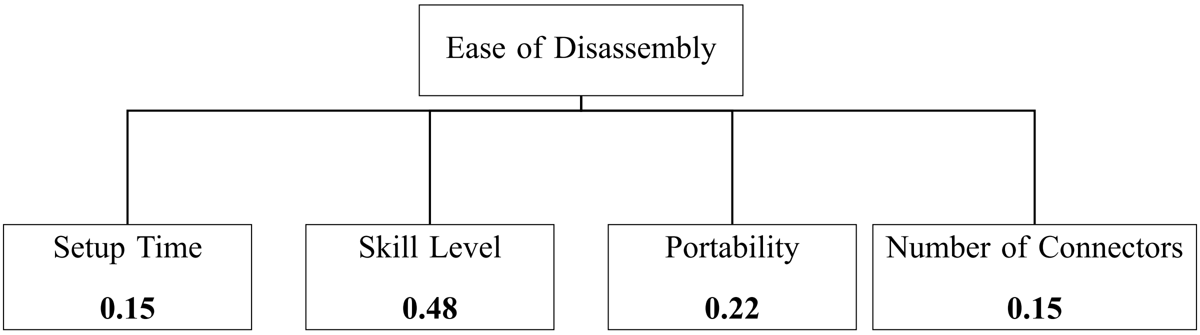

Figure 7: Ease of Disassembly Sub-parameters and Weight Factors

Setup Time

Time to install tool, control the equipment, take precautions for safety and arrange settings.

Category	Time Range	Description	Score
Low Setup Time	≤ 5 minutes	Typically involving basic tools.	1
Medium Setup Time	5-20 minutes	Moderate complexity setup procedures.	0.5
High Setup Time	> 20 minutes	Complex or time-intensive setup requirements.	0

Table 5: Setup Time Classification

Skill Level

This reflects the level of training needed to operate the tool or equipment.

Category	Training Level	Description	Score
Basic	Informal instructions	Informal instructions of how the equipment works.	1
Intermediate	≤ 2 days	Requires basic formal training, maximum two days.	0.5
Advanced	> 2 days	Formal training or certification, more than two days.	0

Table 6: Skill Level Classification

Portability

This reflects the portability of the tools. Tools are categorized based on weight, power source, and operational distance.

Category	**Characteristics**	**Description**	**Score**
High Portability	< 25 kg	Lightweight (under 25 kg), and battery, fuel-powered or cordless tools.	1
Medium Portability	> 25 kg	Tools more than 25 kg without assemblage needing or corded lightweight tools.	0.66
Low Portability	> 10 m reach	Assembled tools that reach more than 10 meters, such as hydro blast.	0.33
Very Low Portability	< 10 m reach	Assembled tools that reached less than 10 meters, such as automated wall saws.	0

Table 7: Portability Classification

Please refer to the assumption table section for tool-related assumptions.

4. Ease of Reassembly

The same sub-parameters are employed; however, the tools used differ.

5. Connection Complexity

This parameter evaluates complexity during the construction and deconstruction phases.

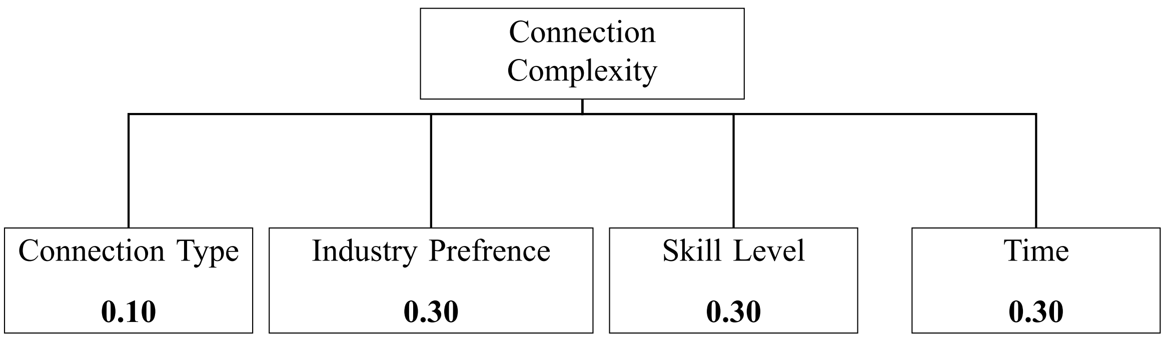

Figure 8: Connection Complexity Sub-parameters and Weight Factors

Connection Type

This evaluates the force transfer mechanism of the connection

Category	Description	Score
Pinned Connections	Allow rotation but restrict translation; transfer only shear forces.	1
Semi-Rigid Connections	Partially restrain rotation and transfer limited moment and shear forces.	0.5
Rigid Connections	Transfer both moment and shear forces. Rotation is fully restrained.	0

Table 8: Connection Type Classification

Industry Preference

Each company has its specialization and preference in connection types.

Category	Description	Score
Common	The majority of companies in the Netherlands are familiar with this type of connection and apply it regularly.	1
Less Common	The majority of companies in the Netherlands are familiar with this type of connection but do not apply it regularly.	0.5
Not Common	Most companies in the Netherlands are unfamiliar with this type of connection.	0

Table 9: Preference Classification

Skill level

This reflects the level of training needed to operate the tool or equipment.

Category	Training Level	Description	Score
Basic	Informal instructions	Informal instructions of how the equipment works.	1
Intermediate	≤ 2 days	Requires basic formal training, maximum two days.	0.5
Advanced	> 2 days	Formal training or certification, more than two days.	0

Table 10: Skill Level Classification

Time

This evaluates the total time of both disassembly and reassembly processes. The time scoring function can be defined as:

$$f(t) = \begin{cases} 1 & \text{if } t \leq 120 \\ 2 - \frac{t}{120} & \text{if } 120 < t \leq 240 \\ 0 & \text{if } t > 240 \end{cases} \tag{10}$$

where t is the sum of disassembly and reassembly time in minutes.

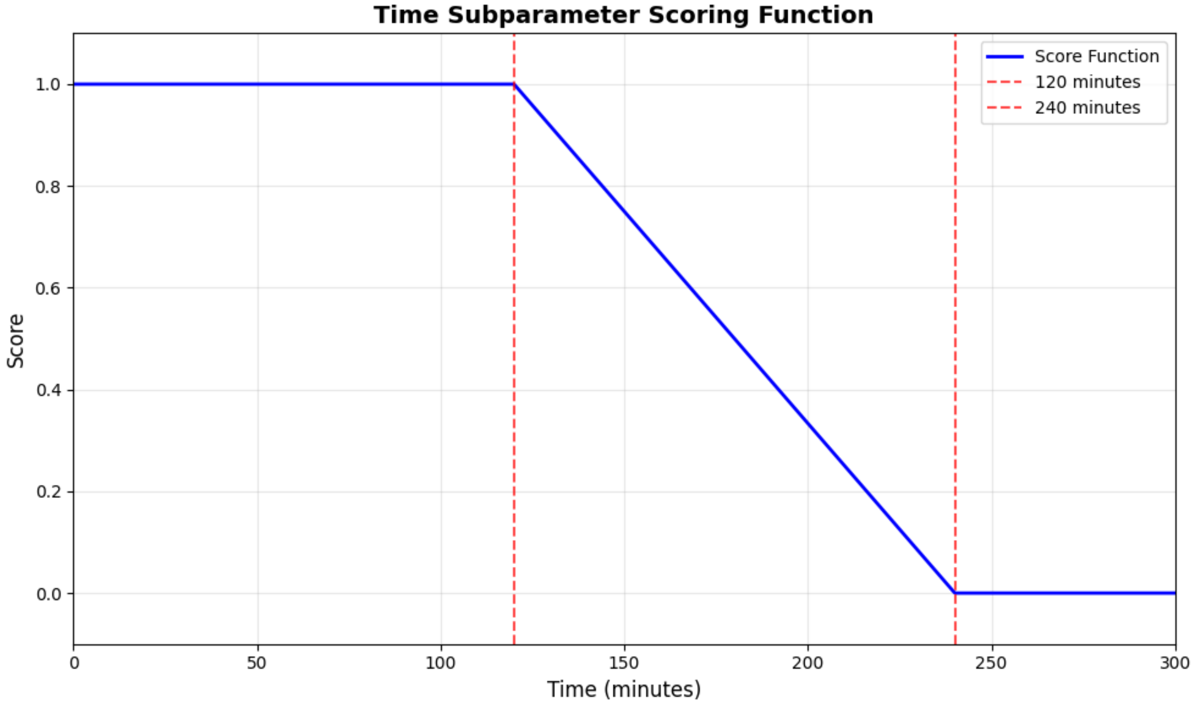

Figure 9: Time Score Graph

6. Prefabrication Degree

This measures the extent to which the connection is produced in a factory. It is calculated as the ratio of pre-fabricated area to joint area.

Prefabrication Degree

This parameter evaluates the extent of prefabrication in the connection system.

.

$$S_{\text{prefab}} = \frac{A_{\text{prefab}}}{A_{\text{joint}}} \tag{11}$$

where:

$$\begin{aligned} S_{\text{prefab}} &= \text{Prefabrication degree score} \\ A_{\text{prefab}} &= \text{Area of prefabricated parts} \\ A_{\text{joint}} &= \text{Total joint area} \end{aligned}$$

7. Number of Steps and Time

This sub-parameter measures the number of procedural steps and the time required for both disassembly and reassembly processes.

Number of Steps

This sub-parameter evaluates the number of steps.

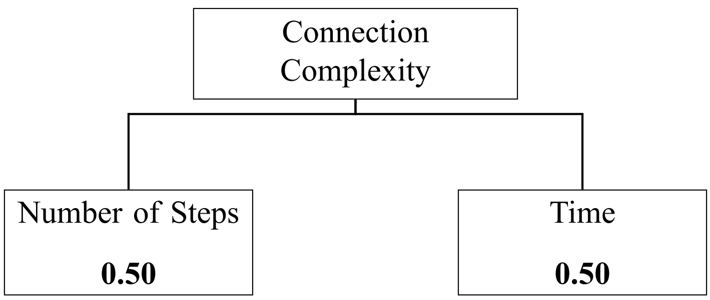

Figure 10: Number of Steps and Time Sub-parameters and Weight Factors

The number of steps scoring function is defined as:

$$f(n) = \begin{cases} 1 & \text{if } n \leq 15 \\ \frac{60-n}{45} & \text{if } 15 < n < 60 \\ 0 & \text{if } n \geq 60 \end{cases} \tag{12}$$

where n is the total number of steps in the disassembly process.

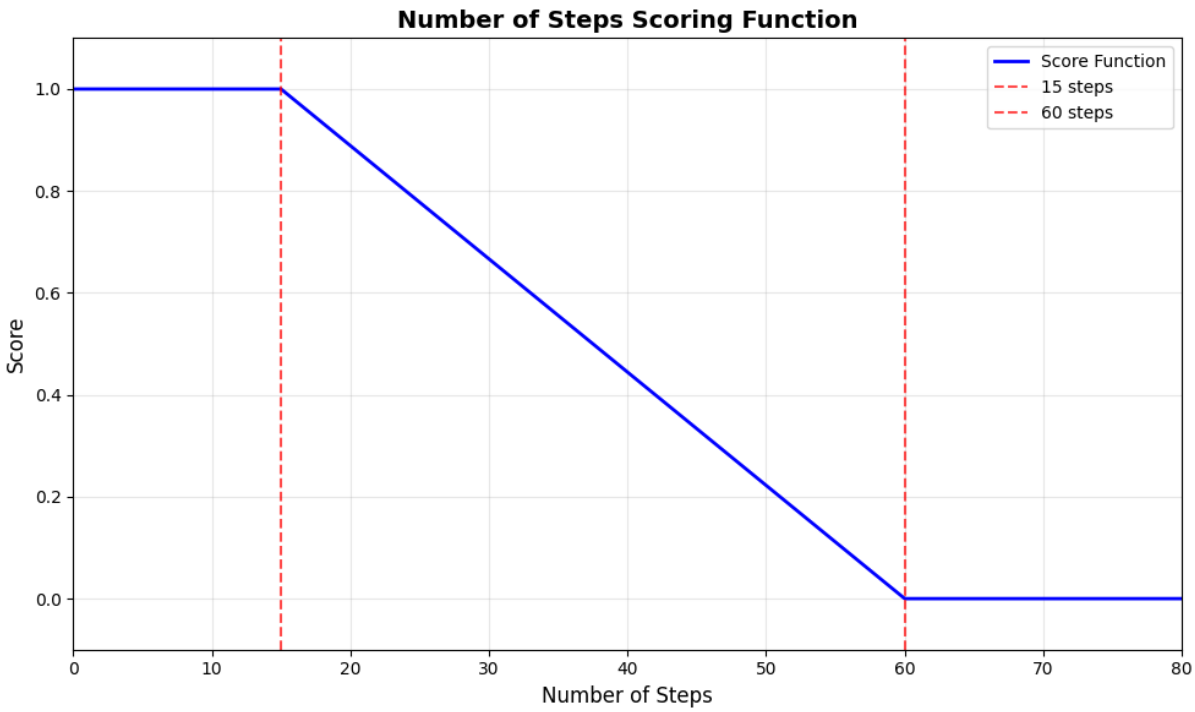

Figure 11: Number of Steps Graph

Time

This evaluates the total time of both disassembly and reassembly processes. The time scoring function can be defined as:

$$f(t) = \begin{cases} 1 & \text{if } t \leq 120 \\ 2 - \frac{t}{120} & \text{if } 120 < t \leq 240 \\ 0 & \text{if } t > 240 \end{cases} \tag{13}$$

where t is the sum of disassembly and reassembly time in minutes.

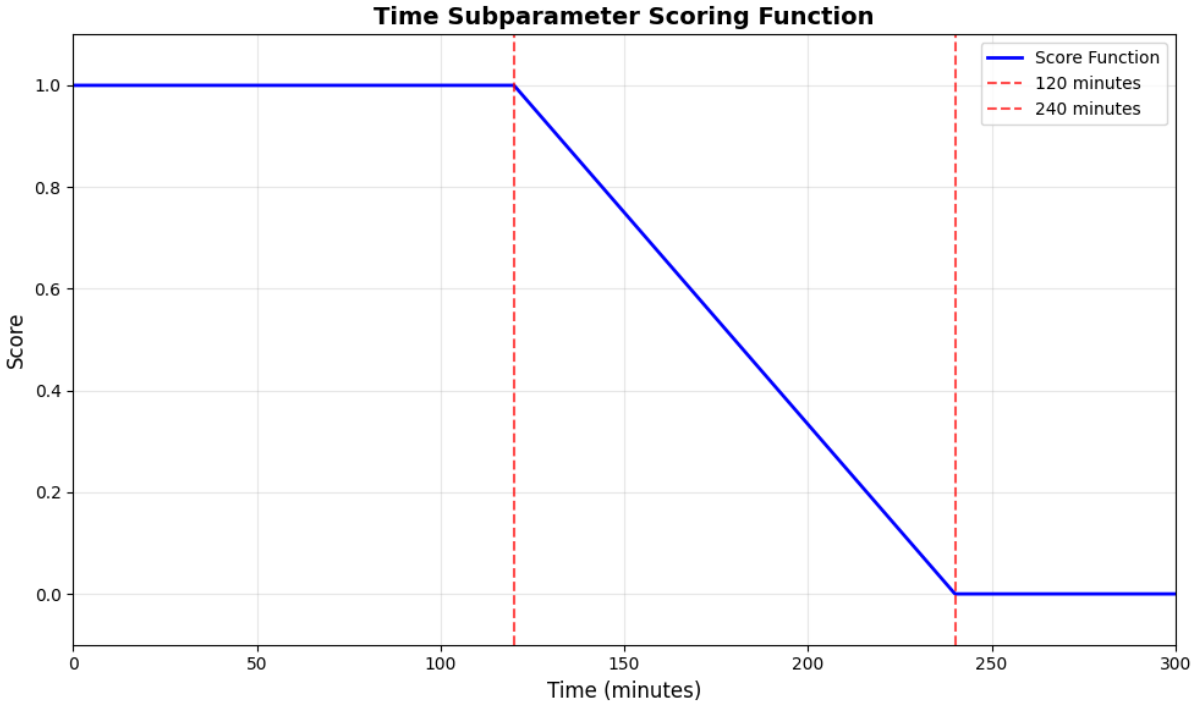

Figure 12: Time Score Graph

8. Accessibility

This parameter evaluates how easily workers can reach and access connections during disassembly operations.

Accessibility	**Score**
Non-accessible standard connections	0
Partially accessible standard connections	0.25
Non-accessible DFD connections	0.5
Partially accessible DFD connections	0.75
Accessible DFD connection	1

Table 11: Accessibility Classification

9. Tolerance

This parameter evaluates the dimensional precision requirements and allowable variations in connection components during assembly and reassembly operations. The tolerance scoring function is defined as:

$$f(t) = \begin{cases} 0 & \text{if } t < 10 \text{ mm} \\ \frac{t-10}{40} & \text{if } 10 \leq t \leq 50 \text{ mm} \\ 1 & \text{if } t > 50 \text{ mm} \end{cases} \tag{14}$$

where t is the tolerance value in millimeters.

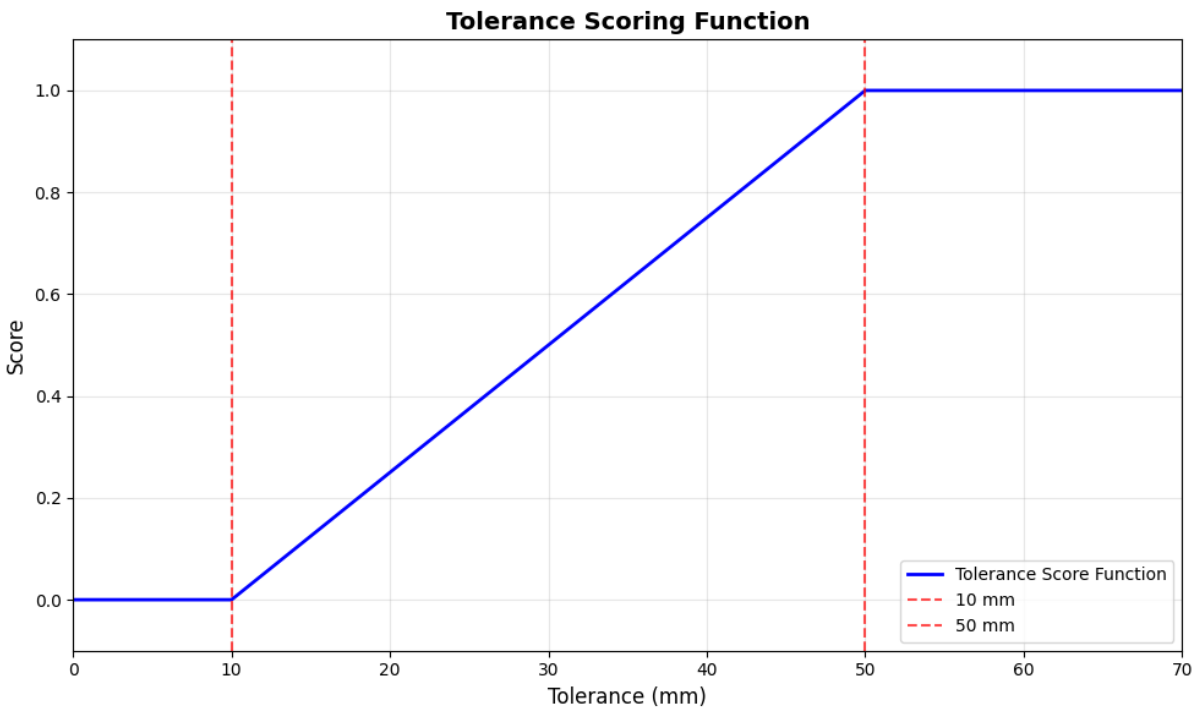

Figure 13: Tolerance Scoring Graph

10. Size

This parameter evaluates the joint area of the connection.

The size scoring function is defined as:

$$f(A) = \begin{cases} 1 & \text{if } A \leq 600 \text{ cm}^2 \\ \frac{2500-A}{1900} & \text{if } 600 < A < 2500 \text{ cm}^2 \\ 0 & \text{if } A \geq 2500 \text{ cm}^2 \end{cases} \tag{15}$$

where A is the joint area in square centimeters.

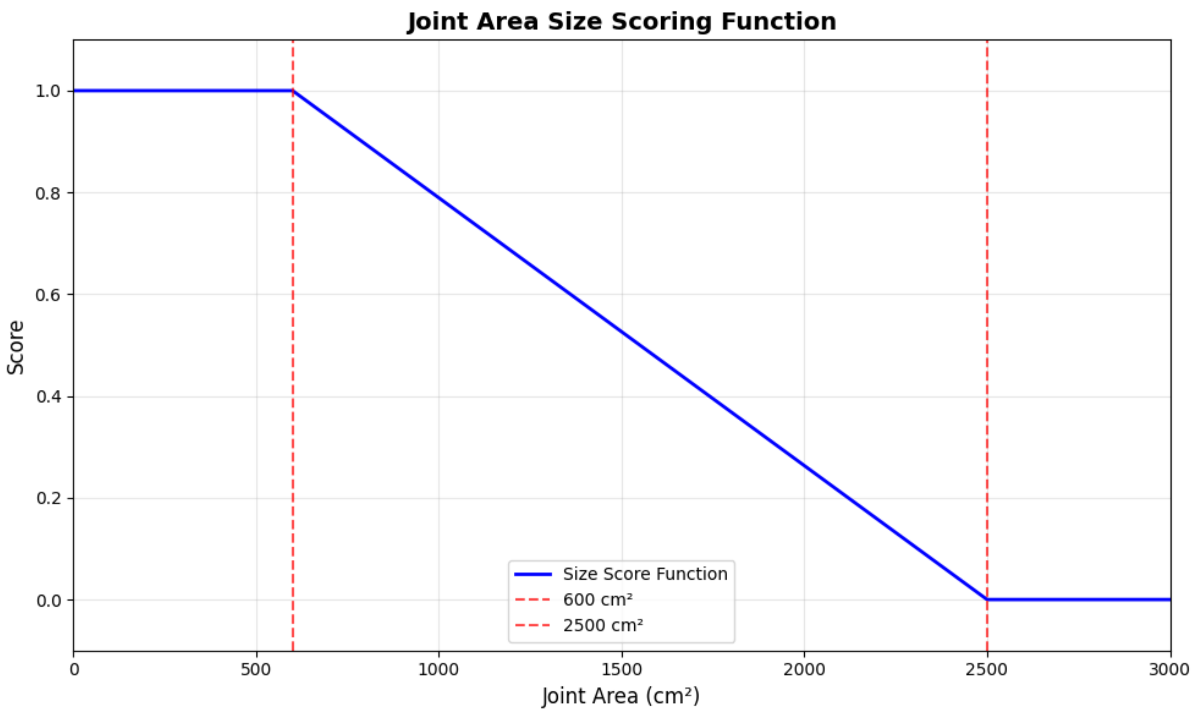

Figure 14: Size Scoring Graph

11. Structural Strength

This parameter evaluates the connection strength based on the strength ratio (SR) and connection characteristics. The strength ratio is defined as:

$$SR = \text{Minimum of } \left(\frac{M_r}{M_d}, \frac{V_r}{V_d}, \frac{N_r}{N_d} \right) \tag{16}$$

where:

- M_r, V_r, N_r = Resistance moment, shear, and axial force
- M_d, V_d, N_d = Design moment, shear, and axial force

Connection Classification:

Strength Category	Consequence Class	Fixed	Partially Fixed	Pinned
Strong (Score = 1.0)	CC3	≥ 1.35	≥ 1.30	≥ 1.25
	CC2	≥ 1.30	≥ 1.25	≥ 1.20
	CC1	≥ 1.25	≥ 1.20	≥ 1.15
Moderate (Score = 0.5)	CC3	$1.25 \leq SR < 1.35$	$1.20 \leq SR < 1.30$	$1.15 \leq SR < 1.25$
	CC2	$1.20 \leq SR < 1.30$	$1.15 \leq SR < 1.25$	$1.10 \leq SR < 1.20$
	CC1	$1.15 \leq SR < 1.25$	$1.10 \leq SR < 1.20$	$1.05 \leq SR < 1.15$
Weak (Score = 0.0)	CC3	< 1.25	< 1.20	< 1.15
	CC2	< 1.20	< 1.15	< 1.10
	CC1	< 1.15	< 1.10	< 1.05

Table 12: Structural Strength Classification Based on Strength Ratio

Consequence Classes:

- **CC3:** High consequence class
- **CC2:** Medium consequence class
- **CC1:** Low consequence class

Connection Types:

- **Fixed:** Rigid connections that transfer both moment and shear forces
- **Partially Fixed:** Semi-rigid connections with limited moment transfer
- **Pinned:** Connections that allow rotation but transfer only shear forces

12. Design Documentatiton

Design documentation includes structural drawings and calculation reports.

Availability Category	Description	Score
Full Digital Availability	All drawings and calculation reports are accessible and stored digitally.	1.0
Full Paper Availability	All drawings are accessible in paper format and readable.	0.9
High Digital Availability	80 percent or more of the drawings and reports are accessible. Some minor details are missing.	0.8
High Paper Availability	80 percent or more of the drawings and reports are accessible and can be readable. Some minor details are missing.	0.7
Moderate Digital Availability	Equal to or more 40 percent and less than 80 percent of the drawings and reports are accessible digitally. Some details are missing.	0.6
Moderate Paper Availability	Equal to or more 40 percent and less than 80 percent of the drawings and reports are accessible and can be readable. Some details are missing.	0.5
Low Digital Availability	Equal to or more than 20 percent and less than 40 percent of the drawings and reports are accessible digitally. Some details are missing.	0.4
Low Paper Availability	Equal to or more than 20 percent and less than 40 percent of the drawings and reports are accessible and can be readable. Some details are missing.	0.3
No Availability	Less than 20 percent of drawings/reports are available.	0.0

Table 13: Design Documentation Classification

Assumption Table

Below you can find the tool assumptions.

Tool	Setup Time	Skill Level	Portability	Minor Damage	Major Damage	Precision
Disc Saw/battery	Low	Basic	High	Moderate	Moderate	High
Corded Disc Saw	Low	Basic	Medium	Moderate	Moderate	High
Petrol Ring Saw	Low	Intermediate	High	Moderate	High	Moderate
Corded Ring Saw	Low	Intermediate	Medium	Moderate	High	Moderate
Petrol Chain Saw	Low	Intermediate	High	Moderate	High	Low
Corded Chain Saw	Low	Intermediate	Medium	Moderate	High	Low
Walk behind floor saw	Low	Intermediate	Medium	Low	Moderate	Moderate
Automated Wall Saw	High	Intermediate	Very Low	Low	Low	High
Hydro blast	High	Advanced	Low	High	Low	Low
Blow torch	Moderate	Intermediate	High	Low	Low	Moderate
Demolition Hammer	Low	Basic	Medium	High	Moderate	Low
Torque Wrench	Low	Basic	High	Low	Low	High
Angle Grinder	Low	Basic	High	Moderate	High	-
Hydraulic Piston	-	-	-	High	Low	High
Welder	Moderate	Intermediate	High	Low	Low	Moderate
Diamond Drill	Low	Basic	High	Very High	High	Moderate
Impact Wrench	Low	Basic	High	Very High	Low	High
Rotary Hammer	Low	Intermediate	High	Very High	Moderate	Low

Table 14: Tool Assumption Table