# Supporting Sustainable Product Design: A Case Study with InDeaTe Tool and Template at Washington State University, Pullman, WA

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**Abstract** InDeaTe Tool and Template is a sustainable design support, aimed at imbibing and improving the sustainability considerations in any design. This paper presents a case-study on the 'design of a product' as a sustainable solution for the problems faced currently while making Wooden-fibre boards at the WSU on-campus facility, where an array of boards are made with wood-based materials, to the specifications of its various applications. The objective was to design a product in which the boards can be formed to completion—from laying, orienting to compressing in the hot press, without moving it from one station to another, ensuring care from damage and preferably with minimum human effort. The case study discussed in this paper, illustrates how the use of InDeaTe Tool improved the considerations of all dimensions of sustainability in a product and could be used for design of more sustainable products.

**Keywords** Eco-Design · Design for sustainability · Enabling technologies and tools · InDeaTe tool and template

## 1 Introduction

The Composite Materials and Engineering Centre, Washington State University, Pullman is an on-campus facility for designing, manufacturing and testing a number of wood based products, predominantly boards, to specifications as required for a

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number of applications and use. Currently these boards are made by hand, making the process tedious, labour-intensive, prone to damage while moving from one work station to another and most importantly exposes the people involved to industrial resins, that are toxic in nature, and dust from the wood-material. The resultant hand-made boards also have a lot of wastage from the sides where the board density is not even and needs to be cut. Another challenge is the thirty-minute window within which the entire process of laying the boards by hand to moving it into the hot press must be completed as the resin begins to lose its properties.

This case study illustrates the design of a product for easing the process of manufacturing wood-based boards, with improved sustainability considerations by using the InDeaTe Tool and Template. The resultant design is evaluated against the existing solution, to assess the improvement in sustainability considerations with the use of Tool.

## 2 Case Study: Overview

The goal is to assess the improvement in the sustainability consideration of the re-designed solution and in turn, the effectiveness of the InDeaTe Tool.

This is an exploratory Case Study and key questions studied are;

- Does the sustainability consideration improve with the use of the InDeaTe Tool and Template?
- How effective is the InDeaTe Tool and Template in supporting designer?

The underlying proposition of this case study is that the use of the InDeaTe Template and Tool improves the sustainability consideration of a product by supporting designers in formulating, iteratively improved List of Requirements with high sustainability-focus.

### *2.1 Problem Brief*

OSB i.e., oriented-strand board, is made of flat strands of wood approximately half an inch in width and around four to six inches in length, oriented parallel to provide maximum strength. Another resultant product is the MDF (medium-density fibre) Board, which is made of fine fibres of wood clumped together like cotton. Few boards are made with a mix of materials while some are made in layers, later pressed into one. Certain boards are also designed into certain two or three-dimensional geometries for specific use or properties such as, increased compressive strength.

The existing process of manufacturing, by-hand, the wooden-fibre boards is as follows;

(i) different types of material; i.e., strands for OSB, chips and medium-density fibres for MDF; are resin-atomised in a blender
(ii) the now atomised material, upon volume measure for required board dimension, is spread by hand (also called "chicken-fed") upon a forming box with a metal base plate
(iii) the material is chicken-fed on top of a suspended frame of vanes, adjustable in width, that help orient the strands; or rubbed on strings (banjo box) in case of MDF
(iv) once spread, the material is manually pressed to compact into a mat which is then moved to a scissor lift
(v) finally the mat is pushed into the hot press for the resultant board.

The **objectives** of this exercise is to design a product that eases human effort of making the wood-fibre boards, reduces damage to the mat, and perhaps even improves the board quality. The 'chicken feeding' process of laying as well as the basic input of atomized raw materials were given as part or constraints of the problem brief.

## 2.2 *Design Methodology*

The Design team followed the InDeaTe design process Template, where iterative GEMS (generate-evaluate-modify-select) activities of design are performed in each design stage while considering each life cycle phases of design.

This design exercise involved the first three design stages and followed the InDeate Template's proposed design process steps to produce the following set of Deliverables, summarised in Table 1.

### 2.2.1 Exercise Duration

Approximately 35 h, Four Days

Day 1—Introduction of team members, Design problem and Site visit of the Composite Materials and Engineering Centre for Client interaction with Robert Duncan, Research Coordinator and IAS Quality Manager, and Prof. Vikram Yadama, Associate Professor and Extension specialist
Day 2—Design Exercise with Tool—Problem Definition and Task Clarification,
Day 3—Conceptual Design and Presentation of concept for discussions
Day 4—Embodiment Design, Design Analysis and Feedback on InDeaTe tool.

### 2.2.2 Participants

The Team Composed of Three PhD Students with Mechanical Engineering and Architecture Backgrounds.

**Table 1** Case study: design methodology

| Design stage | | InDeaTe template: design process steps | Deliverables |
|---|---|---|---|
| Task clarification | 1 | Select system boundary | 1. Preliminary List of requirements often qualitative with some understanding of their relative importance, often qualitative |
| | 2 | Analyse current situation to identify issues (generate requirement) | |
| | 3 | Using the tool/database select sustainability definitions and indicators to be used in the process | 2. Some ideas of how to solve the design problem, noted down for further use |
| | 4 | Evaluate the issues to find the important ones to address (evaluate/modify requirements) | |
| | 5 | Decide on a list of requirements and their relative importance for use the subsequent stages (select requirement) | |
| Conceptual design | 6 | Generate alternative ideas to satisfy each major requirement (generate solution) | 1. A more concrete list of requirements |
| | 7 | Evaluate these ideas to select the most promising ones (evaluate/modify solution) | 2. A list of possible solution-variants that could be used to solve the problem (i.e. satisfy these requirements) |
| | 8 | Integrate these ideas to generate alternative solution principles (generate/modify solution) | 3. An evaluation of these variants for their suitability to satisfy these requirements |
| | 9 | Evaluate these alternatives to select the most promising solution principle (evaluate/select solution) | 4. The solution-principle selected as the most promising for further development |
| Embodiment design | 10 | Develop alternative, concrete configurations of the sub-systems/parts for the solution principle chosen in CD (generate solution): How can each subsystem/part of the solution principle be embodied? What are the other ways it can be embodied? | A more concrete list of requirements<br>A list of possible solution feasible configurations that could be used to embody the solution principle |

## 2.3 Analysis Methodology

For the analysis of the effectiveness of the InDeaTe Tool and Template, first the design solution conceptualised was assessed following which participants analysed the effectiveness of the Tool from their experience in the design exercise.

#### 2.3.1 Assessment of Design with Respect to Benchmark

The final design selected as concept was assessed by Client for the following;

(i) The **Criteria** for the assessment of the design and in turn the Tool are;

- Satisfaction of Requirement
- Improvement of Sustainability consideration

(ii) **Data for analysis:** The resulting design is analysed with respect to the existing design, as benchmark, and data is in the form of List of Requirements, design sketches, design specifications and other documents.

(iii) **Units of analysis**: Qualitative analysis was performed by subject-matter experts to assess two aspects of the design;

- *High, medium, low, zero* satisfaction of requirements
- *Significantly improved, improved, not improved* Sustainability consideration

#### 2.3.2 Analysis of Effectiveness of Tool

A retrospective analysis of the effectiveness of the InDeaTe Tool and Template was conducted via a Questionnaire posed to the participants.

### *2.4 Limitations of the Study*

- The design exercise is conducted with one team performing a single-instance of design with use of InDeaTe Tool and Template. However, multiple case studies have been performed across domains to assess the same and the analysis results were found positive and corroborative.
- Due to the dearth of a parallel exercise as control, the original design has been used as benchmark to asses the sustainability improvement of the new design. And though it may be argued that there is always scope for improvement upon an existing design, the improvement proves that the Tool can be used to re-design existing issues effectively.

### *2.5 Key Findings of the Study*

- The InDeaTe Template and Tool is effective for improving sustainability considerations in designs.
- The InDeaTe Template and Tool is effective in supporting the designer during the design process.

# 3 Literature Review

## 3.1 Relevance and Need for a Holistic Support

Literature presents a number of sustainability focussed design support are available but most of them are for assessment and evaluation; such as the Swiss Ecoscarcity methods (Ecopoints). While certain tools such as DFE Workbench though well integrated with Solidworks CAD tools, is able to support designers only with respect to the specific, in this case environmental, aspects of a design. There are also design methods that are developed that support only a specific Life Cycle Phase such as the Use-phase [7].

Literature also notes the existing "interaction of methods and tools at various steps in the process" of design and further stresses on the need for interaction between design methods and computer-aided tools to support decision-making [8]. Lopez-Mesa [9] enumerated potent findings about the knowledge and use of design methods in practice and highlighted that only a few methods are 'widely and systematically used' while most are unaware of the availability of other methods and believe that abundance of time is required. However, she notes that implementation of methods provides support to an array of tasks during the design process and leads to consideration of a large number of ideas. Lopez-Mesa further stresses on the increased positive contribution by a method upon the design when it is in a computer based system [9].

Thus, there is need of a computer-based support that encompasses all three dimensions of sustainability—society, economy and environment—across the entirety of the Life cycle of the design and addresses the need for improving sustainability of existing systems, with the systematic integration of methods and tools used prolifically in practice.

## 3.2 InDeaTe Tool and Template: A Novel, Holistic Design Support

InDeaTe Template and Tool, is a knowledge-driven Sustainable Design process support, aimed at imbibing and improving the sustainability considerations in a design. It comprises of two elements—a sustainable design process Template, and a sustainable Design Database—that work synergistically to support the designer on a user-friendly, computer interface. The Template and the Design Database ontology is based on the ACLODS holistic framework [1] which proposes dimensions—Activities, Criteria, Life cycle phase, Outcome, Design Stage and Structure—essential for life cycle development of a design.

The InDeaTe design process Template offers an overview of the design process and provides a generic guideline to follow as the design process is carried out. There

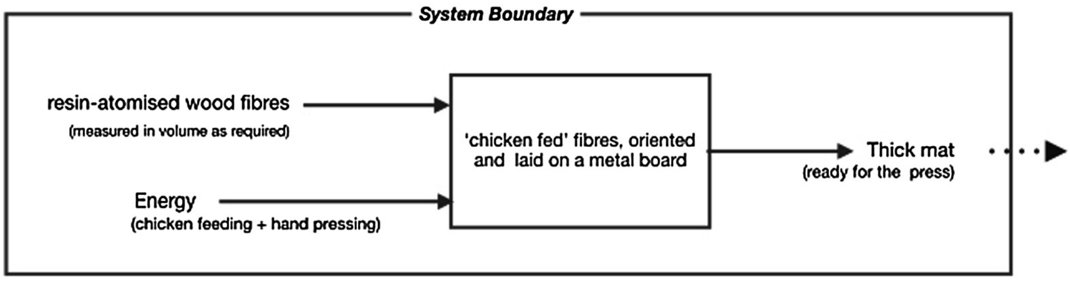


**Fig. 1** Representation of system boundary

are four stages of design—Task Clarification, Conceptual Design, Embodiment Design and Detail Design [2]. And every design has five Life cycle phase, which are; Material, Production, Distribution and Transportation, Use and After Use. The Template encourages designing for the entire lifecycle of the system, with the aim of making it more sustainable. It guides the designer to perform suitable Activities of design, i.e., generate-evaluate-modify-select (GEMS) in each Design stage, at the intersection of every Life Cycle Phase. This is represented in the Fig. 1.

The Design Database is a comprehensive knowledge-base. It consists of a sub-database of Sustainability Definitions and Indicators, that help clarify the design task at hand with respect to the sustainability perspective while the corresponding sustainability Indicators prompt the suitable sustainability considerations in the design. This is further linked to a sub-database of Design Methods and Tools, that aids the designer in the design process to achieve those sustainability considerations.

## 4 Design Exercise

The team used the InDeaTe Tool and Template to perform the exercise. The designers began to navigate through the Tool upon selecting 'Product' category for type of design, as was made explicit by the clients.

### *4.1 Task Clarification Stage*

In this stage, the design team well defined the problem statement with the intent to identify a preliminary list of requirements.

Step 1: The design team followed the Template and **Selected a System Boundary**, as represented in Fig. 1. Upon client interaction it was clarified that the resin material, blenders and the resin-atomising technique were clearly out of the design scope. The product-system boundary was identified to be from the point of resin-atomised material being available for forming till the point of the material-mat being in the hot press.

Step 2: The design team **identified other constraints**; (i) maximum time to form the mat and move it to press (30 min) and (ii) the maximum dimension of a mat (*8′ × 4′, variable height allowed*), were definite constraints.

However there were many **scopes of intervention** that were noted, such as;

- the manner of transferring the resin-atomised material from blender room,
- the manner of dispensing the resin-atomised material, (*noted: chicken-feeding is highly effective*)
- the manner of orienting the material, (*noted: the vanes are effective but edges are brittle*)
- the manner of moving the ready mat, (*noted: lifting the mat causes damages*)
- the in-use equipment such as vanes and forming boxes.

Next, the design team **analysed the current situation to identify issues** and generated (G) requirements

The existing system could be decomposed into the following tasks—the orienting and laying of resin-atomised material, compressing the material into a mat by hand, and moving of the mat onto the scissor-lift to be rolled into the hot press.

And each of these tasks had certain lifecycle issues that required to be addressed, such as;

– The orienting and laying had a Manufacturing-phase issue where the quality of the product (mat) was not consistent. However it was clarified that the forming boxes and vanes for made of wood and metal, has long life of up to 20 years and can be re-used several times.
– The laying and compressing the material by hand had Use-phase issues, as the person involved gets exposed to the resin and dust, and causes posture-related issues.
– The moving of the mat onto the scissor-lift to be rolled into the hot press, again had a predominantly Use-phase issue with the persons involved being responsible for the timely and un-damaged mat being moved. And often this is contributed significantly to the waste generated as delayed or damaged mats cannot be re-done due to hardening of resin.

In order to well-define the problem, the designers **formulated a Solution Neutral Problem Statement (SNPS)**—*To design a device that lays resinated wood chips/strands/fibres as a mat with uniform depth and orientation, adjustable for various sizes, within a time constraint, ready to be moved into a press, and operated with minimal human effort.*

Step 3: The design team then turned to the Tool and chose the **TBL scope—society and environment**, for this particular design and argued that in a Design and testing facility such as this, economics was not a critical concern. The Tool has a list of Sustainability Definitions—a repository of over 80 definitions and principles available on the tool's design database, from which the designers **selected Sustainability Definitions, Principles and Indicators** for their design process. The team found the World Bank [3] and the Sustainable Seattle [4] definitions to be appropriate, based on the aspects of TBL that each encompassed and in turn this was used for scoping and directing the motivations of the design via Indicators.

Upon selecting the definitions, the Tool further provided a **set of Sustainability Indicators** that would be used to operationalise the selected definitions. These were;

- Living condition (Social Indicator): Rates of injury, occupational disease, [5];
- Waste generation (Environmental Indicator): Generation of general waste, Generation of hazardous waste [6];

Th Template does not dictate consideration of constraints, including critical ones such as as cost and time, are left to the designers depending on their priorities and requirements.

Step 4: These Indicators persuaded the generation of requirements and the design team pragmatically conducted an **Evaluation of issues** to find the important ones to address. As a result, some Preliminary Requirements were generated (G) upon evaluation (E) and few modifications (M);

- eases human effort of making the wood-fibre boards (from laying, compressing to moving of mat into press)
- improve human working conditions
- reduce damage to the mat caused due to multiple instances of moving (from forming box to scissor lift to press), and
- improves the board quality (orientation of fibres and uniformity of depth)

Step 5: And to **prioritise these requirements**, the design team selected **Quality Function Deployment or QFD Method** and used the **'House of Quality' (HOQ) tool** that is based on it, illustrated in Fig. 2, from the Design Database.

As a result, the design team met the **Task Clarification Deliverable** of formulating a **Preliminary List of Requirements,** which was;

(i) Improve working condition—exposure and ergonomic
(ii) Precisely oriented wood chips/fibres
(iii) Consistent depth
(iv) Mat easily movable into Press
(v) Ease of use
(vi) Minimal Wastage: Maintain spreading time (limit of 30 min)
(vii) Minimal Wastage: Avoid brittle edges

## *4.2 Conceptual Design Stage*

In this stage, the design team explored a number of solution-variants and worked towards selecting the solution-principle or "concept".

Step 6: The team **generated (G) alternative ideas** to satisfy each major requirement and to do so selected the **Brainstorming** Method from the Database.

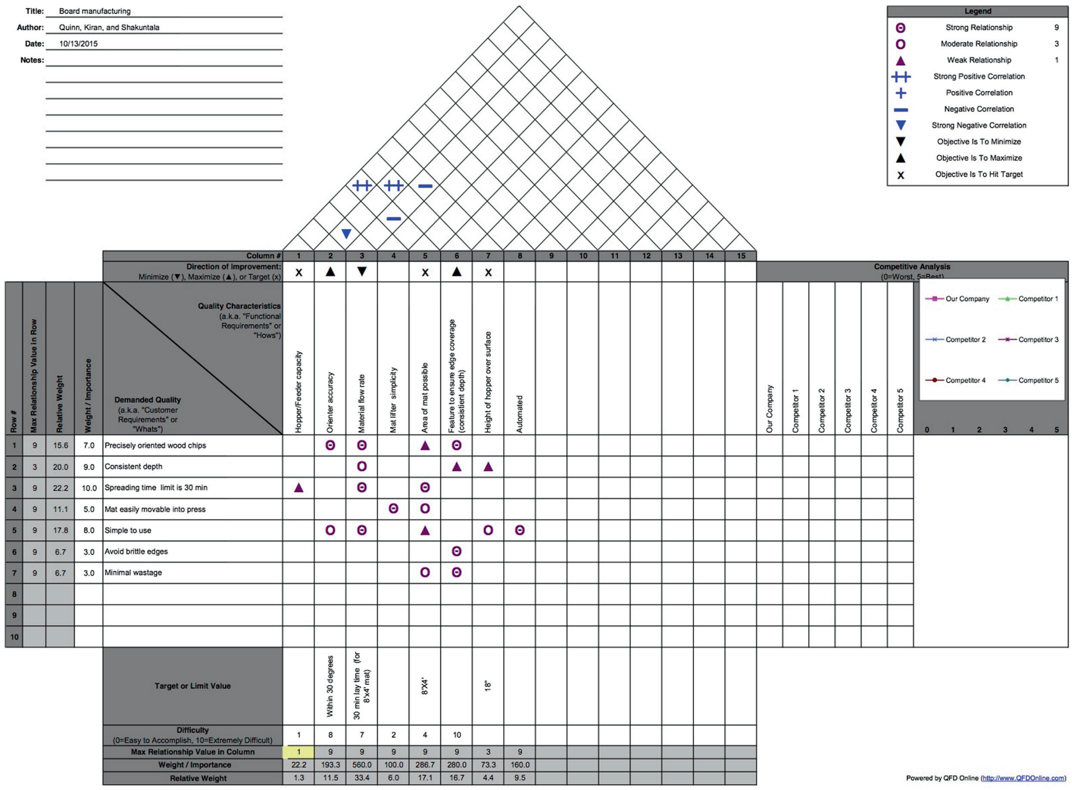


**Fig. 2** House of quality for QFD

The result was a number of ideas for each of the requirements, decomposed as sub-functions, as given below;

– Sub Function 1.1: ALIGNMENT of Material (resinated)

  vanes v/s disc
  magnetic
  blow air through slot
  Funnel/s in parallel—line opening, oscillation
  single hopper (like a 3D printer) in X-Y axes
  accordion like walls to physically align [& vary in size]

– Sub Function 1.2: LAYING (chicken feeding)/Spreading

  oscillating base
  a shaking pourer on top of the aligning device

– Sub Function 2: PRE-PRESS to form mat

  rolling pin {issue: alignment skewed; may require shaping}
  panini press

– Sub Function 3: MOVE to Press

  Form inside the press
  Scissor-lift table → motorise the rollers
  Conveyor

Step 7 and 8: These ideas were then evaluated to see which were feasible and which ones would have greater effect. The design team used the **Morphological Chart** Tool, an example given below in Table 3, from the Database. It was further used to combine solutions and generate six solution-variants, namely Q#1, Q#2, K#1, K#2, S#1, S#2, two by each designer with the initials of their names, an example is given below. These variants were sketched as part of the generation/modification of solutions.

Step 9: The design team next, evaluated these alternatives with respect to **LCA (Life Cycle Assessment)** and **MFA (Material Flow Analysis)** Methods, by assessing the sustainability of the solutions based on the following parameters;

– LCA: Use materials with lower environmental impacts, lower energy consumption and with higher recyclability
– MFA: Use materials with higher strengths & longer life to reduce material needs, and use pre-existing parts where possible

From the solution-variants, the solution-principle was eventually selected by the team by using the **Lexicographic Decision rule** from Methods Database, in which the product attributes, developed from the previous list of requirements, were ranked based on their importance and compared. As a result, the design team agreed upon the section of the solution-principle or 'concept' to be embodied.

Thus, the design team fulfilled the **Conceptual Design stage Deliverable** and the concept specifications for the given design problem, illustrated in Fig. 3, is as given below;

- **Single line opening wide-mouth funnel** into which the resin-atomised material is supplied through a tube from the blender room,
- **Oscillating double sieve-plates hopper** lay and align material to form mat,
- Mat is formed on on a table-height **Conveyor**; that moves back and forth as required for desired thickness of mat,
- **Existing forming boxes,** of specified dimension as required, are re-used fitted **with inward slanting walls**, allow thicker material deposit at the edges, and
- **Rolling-pin** along the width of the conveyor, on the other side of the hopper, compresses the mat after removing the forming box, prior to moving into Press.

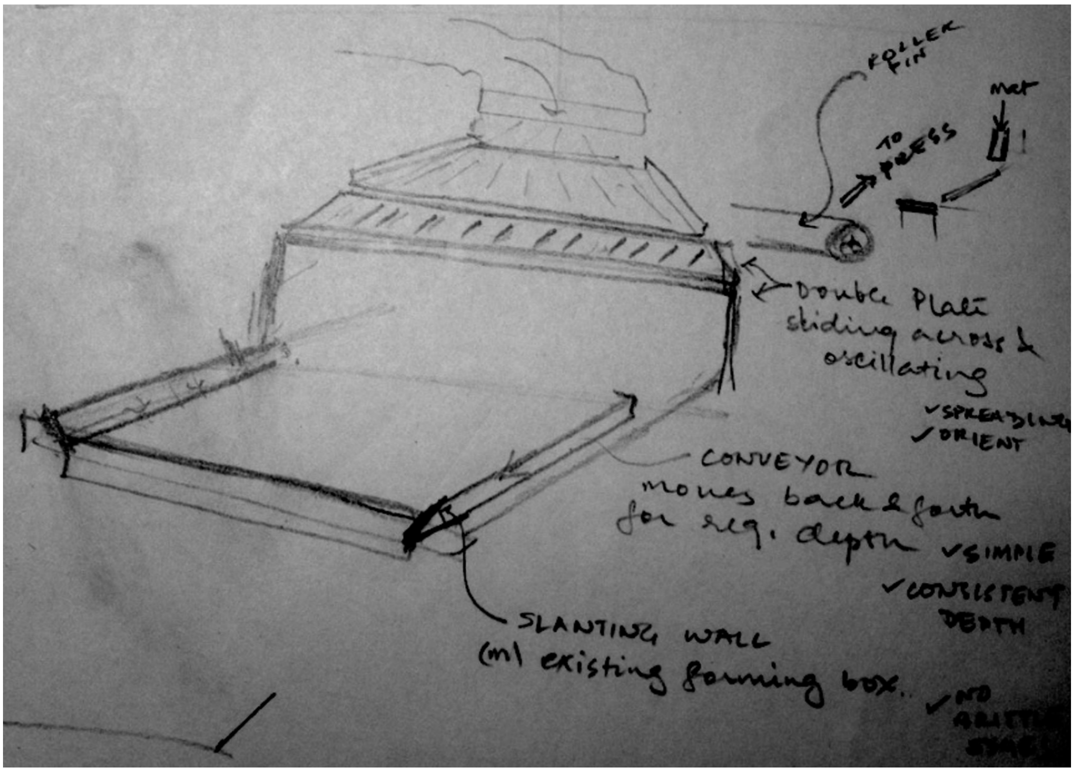


**Fig. 3** Sketch of selected concept

## 4.3 *Embodiment Design Stage*

In this stage, feasible configurations were developed for the selected solution-principle.

Step 10: a number of In order to assess the overall success of the solution-principle as a Product, a **Failure Tree Analysis** as in Fig. 4, from Methods Database was performed by the design team and a refined List of requirements was delivered.

The **Deliverable** of a **Refined List of Requirements** is as follows;

- Conveyor Belt—Rubber or Cloth
- Hopper—aluminium or steel
- Rolling Pin—Steel, hollow pipe
- Internal Material distribution vanes—aluminium

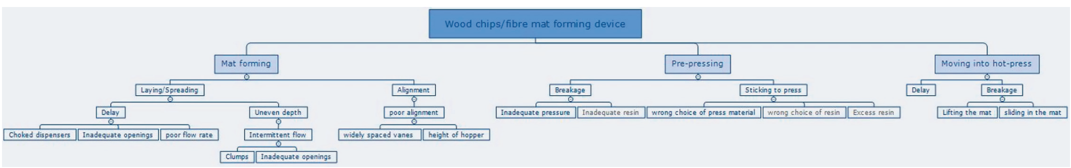


**Fig. 4** Failure tree analysis

- Conveyor motor and Oscillating motor for hopper *(*operational energy to be considered)*
- Structural Frame—Metal and wood
- Pre-existing for re-use;
- Scissor lift
- Material laying plate
- Wooden forming boxes
- Material feeding tube—rubber lined tube *(*resin properties to be considered).*

# 5 Key Findings

## 5.1 Design Assessment

A number of design solution-variants were presented to client to assess the final concept design with respect to the benchmark for requirement satisfaction and improvement of sustainability consideration of the Service system designed. This is presented in Table 2.

The clients' assessment was based on benchmarking the proposed

product design with respect to the existing manufacturing system, and noting the improvements if any. The assessment was conducted based on two criteria; requirement satisfaction—to assess the overall quality of the concept selected to become a "good" and successful product, and sustainability consideration to note the degree of improvement.

The most significant contribution of the InDeaTe tool and template to the design was the formulation of succinct requirements with sustainability as key for consideration, which not only determines product success, but also the overall impact of the product. The InDeaTe tool and template systematic helped identify and refine the requirements to be addressed—such as, working conditions—and in turn, improved the design process with sound guidance of design methods applicable as per stage and activity of design.

The results of the two criteria were in consensus which may be viewed as a validation of the InDeaTe Tool and Template as an effective support to improve sustainability of a service system.

## 5.2 Analysis of Tool

The results of the Questionnaire were overall positive with designers stating that they found the Tool useful

**Table 2** Assessment of design—proposed solution benchmarked to existing solution

| Requirements | Existing solution | Proposed product solution-principle | Requirement satisfaction | Sustainability consideration |
|---|---|---|---|---|
| Improve working conditions—ergonomics and exposure to hazard | – people bend over to work,<br>– ‘chicken feed’ the material by hand | – table height Conveyor,<br>– automated product | High | Improved significantly |
| Precisely oriented wood chips/fibres | – suspended vanes | – Oscillating double sieve-plates hopper | Medium | same |
| Consistent depth | – material laying and required depth done by hand, increase in exposure | – Conveyor moves back and forth as required for desired thickness of mat | Medium | Improved significantly |
| Mat easily movable into Press | – mat would be moved by the persons involved | – Mat is formed on a Conveyor;<br>– Rolling-pin along the width of the conveyor to compresses the mat prior to moving into Press | High | Improved significantly |
| Ease of use | – the resin-atomised material is carried in buckets | – automated<br>– the resin-atomised material is supplied through a tube from the blender room | High | Improved significantly |
| Minimal wastage: maintain spreading time (limit of 30 min) | | – automated system that not only maintains time but efficiently manages it | Medium | Improved |
| Minimal wastage: avoid brittle edges | | – Existing forming boxes (of specified dimension) are fit with inward slanting walls to allow thicker material deposit at the edges | High | Improved |
| | | | **Satisfied** | **Sustainability improved** |

**Table 3** Morphological chart tool

| Design parameters | Solution—variants (S#1) | | | | | |
|---|---|---|---|---|---|---|
| Laying | Vibrating full width hopper | Oscillating base | Hopper moving x-y | Set of parallel hoppers | Single adjustable width funnel | |
| Alignment | Magnetic | Air flow | Line opened funnel | Accordion | Vanes | Rotating discs |
| Pre-press | Rolling pin | Flat plate pressed | Panini press | No pre-press | | |
| Move | Form inside press | Form on scissor lift | Conveyor | Form outside and move in with scissor lift/manually | | |

InDeaTe effectively supported the design team to;

– identify key areas of improvement from the Sustainability Indicators, which behaved as prompts
– integrate various considerations with use of methods
– evaluate and select a “good” concept which satisfies the requirements and achieves improved sustainability considerations

## 6 Conclusions

It was a successful design exercise as the proposed design outcome was a Product with higher sustainability considerations and satisfied all the requirements of the clients without compromising on the quality of the boards. InDeaTe Tool and Template supports designers to improve sustainability of a product and is recommended for design of more sustainable products.

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