MECH 4V96.001: Shop Design

Mechanical Engineering

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ICED 2025 Puzzle

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1) Executive Summary

A large wooden puzzle (Fig 1.1) was designed and fabricated, ready to be transported to Bordeaux, France for the 2023 International Conference on Engineering Design. The 770-piece puzzle will be completed at ICED 2023 and will reveal that the next iteration of the conference, ICED 2025, will take place at the University of Texas at Dallas in Richardson, Texas.

Fig 1.1: Completed Puzzle

2) Problem Definition

At every ICED conference, a clue is given to the attendees regarding the location where the next conference will be held in two years. Dr. Joshua Summers, Department Head of Mechanical Engineering at The University of Texas at Dallas, has requested a large puzzle for use at ICED 2023, which will take place in Bordeaux, France. Upon arrival at the conference, each attendee will receive a backpack containing items for the event. Dr. Summers plans to place one piece of the puzzle in each backpack, and for the puzzle to be completed over the course of the conference. As the puzzle is assembled, it will slowly be revealed that ICED 2025 will take place at Dr. Summers' own university, The University of Texas at Dallas.

3) Project Requirements

Based on the specifications from Dr. Summers, the team compiled a table of requirements for the puzzle. (Fig 3.1)

#	Requirement:
1	The puzzle includes Approximately 750 unique pieces
2	Piece size is around 2x2" (tolerance of 0.25 inches)
3	Materials are Eco-Friendly
4	Puzzle pieces do not exceed 1/8" thick
5	'Design is a Team Sport' is displayed on the completed puzzle
6	Design Society and UTD logos are displayed on the completed puzzle
7	Message showing that ICED 2025 will take place at UTD is displayed on the completed puzzle
8	Disassembled puzzle fits in a carry-on bag on a plane (22"x14"x9")

Fig 3.1: Table of Requirements for the Puzzle Pieces

4) Research

4.1 - Materials

The team investigated three materials for the backing of the puzzle pieces: wood, steel, and acrylic. Since the table of requirements dictated that the puzzle must be eco-friendly, the team dismissed acrylic in the early stages of planning. Though steel is strong and durable, it was deemed too expensive, so wood was selected as the primary material for the puzzle. Birch was then chosen due to its availability, price, and visual appeal.

4.2 - Puzzle Shape

The team discussed fabricating a circular or square puzzle. However, it was agreed that a rectangle was the best option, due to easier fabrication, transportation, and graphic design. Initial designs attempted to maintain a height-to-width ratio of approximately 1:1.618; the golden ratio, due to its historical use in art and design. However, due to the 2x2" constraints for each piece, the puzzle has a height-to-width ratio of 1:1.59.

4.3 - Poster Materials and Adhesives

Of the options available for creating a graphic that could be transferred to a puzzle, the team decided that it was best to professionally print a poster before gluing it to the birch boards. However, consideration was given and dismissed for printing on vinyl as well as printing and engraving directly on the wooden boards. The team did not pursue vinyl due to it being more expensive locally than printing. Then, for printing and engraving on the wood boards, the idea was dropped due to the diminished and potentially monoscale image quality. Satin gloss paper was deemed to be the most visually appealing and professional-looking of the various choices. PVA, neoprene, and two-sided tape were all considered as potential adhesives to stick the paper to the birch boards. Neoprene's high cost and the laborious process of applying tape made PVA glue an easy choice.

4.4 - Poster Design

To produce the picture for the puzzle, the team began by researching photos of UT Dallas. Fig 4.4.1 shows the photo that was agreed to serve as the best backdrop. It was chosen for its bright colors and relatively large amount of free space. This free space would be used to add the Design Society and UT Dallas logos, along with the appropriate messaging to announce UTD as the location of ICED 2025. While a collage of various images was considered, this was discarded in order to produce a cleaner result that felt less cluttered and more cohesive.

Fig. 4.4.1: Photo of UTD[1]

Once the background photo was chosen, the team experimented with permutations of logo placement, wording choice, color schemes, and text types in order to satisfy the design goals of this project. After small focus group testing and a few rounds of approvals, the puzzle graphic design was finalized (Fig 4.4.2).

Fig. 4.4.2: Final Poster Design

4.5 - Cutting Technique

Both jigsaws and ULS PLS6.75 laser cutters were available to the team. Laser cutting was chosen because jigsaws did not have the capability for the tight, smooth-rounded corners needed for a puzzle piece. Also, due to the size of the puzzle and the consistency of the results, laser cutting was deemed to be the best cutting option.

4.6 - Sizing and Aligning

The team's initial plan was to fabricate one large puzzle, comprising around 750 2"×2" pieces. However, restrictions caused by the size of the laser cutter's bed required changes of plan. After some deliberation, the team decided to break the puzzle into ten separate sub-puzzles, each of which would be cut from a single panel. Fig. 4.6.1 shows the dimensions of the ten panels. Each panel contained one tenth of the entire puzzle. Surrounding the image on all sides was half an inch of extra graphic to provide continuity on the edges in case the puzzle cut out of the graphic was not centered and aligned perfectly.

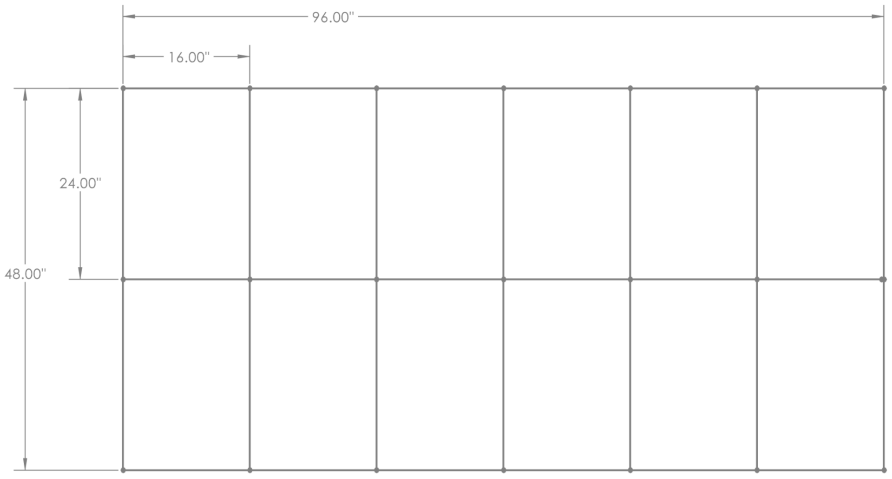

Fig 4.6.1: Puzzle Panel Cutting Diagram

4.7 - Individual Puzzle Design

Each of the ten puzzles were made unique using an online jigsaw puzzle generator[2] and exported as SVG files. The generated SVG files were then converted to DWG files and opened in AutoCAD. Fig 4.7.1 shows the DWG file for puzzle 1 (the top left panel). Each puzzle had dimensions of 11×7 different pieces, resulting in a total of 770 pieces, thus fulfilling the project requirements of approximately 750 uniquely shaped pieces.

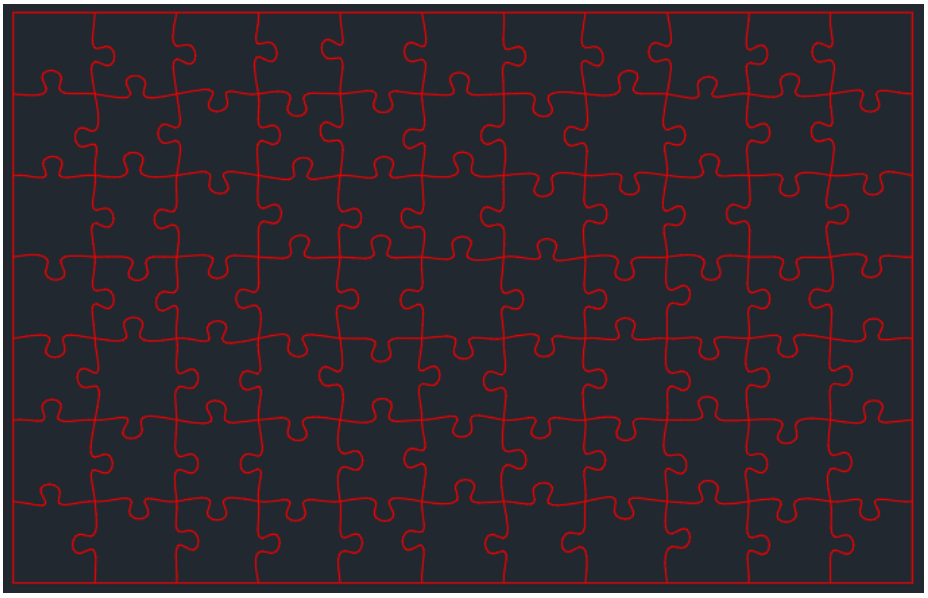

Fig 4.7.1: CAD File for Puzzle 1

4.8 - Morph Chart

The morph chart for the project is shown in Fig 4.8.1.

360	Feature	Type 1	Type 2	Type 3	Type 4	Type 5
5	**Material Type**	Steel	Acrylic	Birch	Maple	Alder
3	**Puzzle Shape**	Square	Circle	Rectangle		
3	**Adhesive**	Neoprene	PVA	Two-Sided Tape		
2	**Printing Type**	Poster	Vinyl			
2	**Cutting Method**	Jigsaw	Laser-Cutter			
2	**Adjoining Technique**	Multiple Puzzles	One Puzzle			

Fig 4.8.1: Morph Chart

4.9 - Critical Design Review

Following the research phase of the project, a critical design review presentation was given on April 14, 2023. In attendance were Dr. Joshua Summers, Dr. Dani Fadda, and the 8 other students in the Shop Design class. The design was approved and was moved into the implementation stage.

5) Implementation

5.1 - Panel Ordering and Key

Several design choices were made in order to reduce the assembly time, given that the main intent of the puzzle was to convey the location of the upcoming conference, not to have engineers spending hours constructing a jigsaw puzzle. First, all of the pieces of each of the ten constituent sub-puzzles were engraved with an identifier that marked them as part of a certain puzzle. Next, a key to these identifiers was engraved on a legend that showed the relative position of each sub-puzzle. Finally, the orientation of these engraved identifiers on the pieces themselves were kept constant in order to further reduce the assembly time by reducing the degrees of freedom of each piece.

The identifiers chosen were years in which the conference had been held. In the legend, the identifiers are matched to the city in which the conference had been held in that year. For example, consider the puzzle on the top left. Each piece of this puzzle was engraved with the year 2023. This year, the conference will take place in Bordeaux, France. On the legend, the city in the top left position is Bordeaux. In this manner, it is conveyed that each puzzle with the engraving “2023” belongs to the puzzle situated in the top left. The CAD model for the engraving of the legend is shown in figure 5.1.1, with the manufactured product shown in figure 5.1.2.

Fig. 5.1.1: Puzzle Key CAD File

Fig 5.1.2: Final Puzzle Key

In order to engrave the numbers on the back of the puzzle, separate CAD files were created with the numbers correctly spaced out in matrix form. Fig 5.1.3 shows a sample file, for the year 2021.

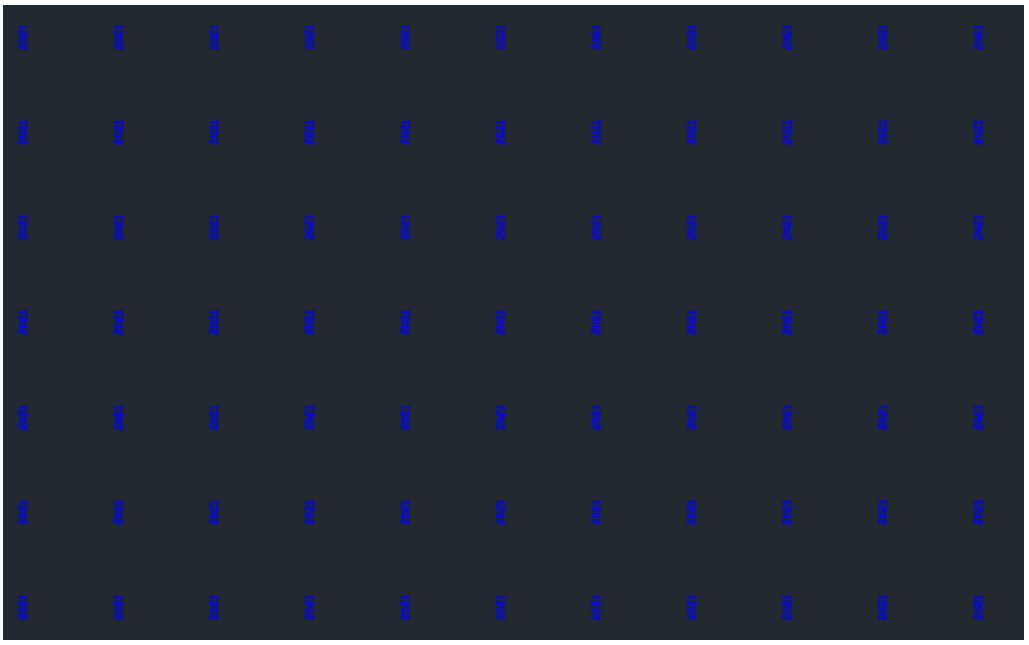

Fig 5.1.3: Number Engraving File

5.2 - Testing

Before any of the final puzzles were cut, testing was conducted to determine the quality of the engravings and the kerf of the laser cutter, the size of the gap between pieces that the cutter burns away. Fig. 5.2.1 shows results of some of the early tests.

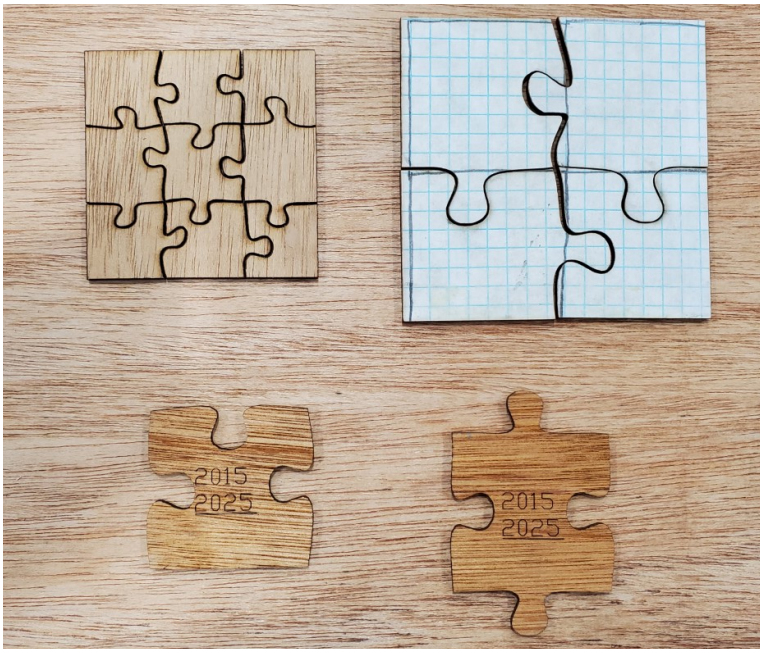

Fig. 5.2.1: Early Test Results

The top left represents a test of our puzzle graphic software and the tolerancing of the tabs in each piece. The top right is a full scale prototype of the pieces. The bottom two tabs represent our engraving tests and perfecting our alignment methodologies.

As testing continued, it became apparent that the laser cutter regularly left a brown residue and burn marks on the paper after it was cut. Fig. 5.2.2 shows an example of the staining that often occurred on the pieces after cutting. The higher the intensity of the laser, the darker the color of the stain.

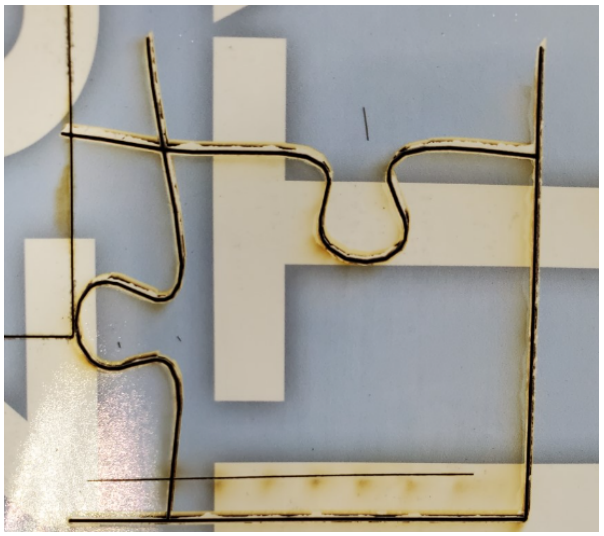

Fig. 5.2.2: Staining on a Puzzle Piece

Testing was conducted to identify the optimal laser strength to minimize staining, ensure that the wood was cut all the way through, and minimize manufacturing time. The power of the laser, cutting speed, and material type were individually adjusted. The cleanest results that cut all the way through the panels at an acceptable manufacturing time came from a laser at 25% power and 2.7% of maximum speed. These settings are shown in Figure 5.2.3.

Fig 5.2.3: Optimized Settings for Cutting

5.3 - Application of Adhesive

The posters were printed locally and carefully glued to the birch boards using the PVA wood glue mentioned previously. They were then left overnight under a heavy weight to ensure that they were adequately adhered and flattened. Fig. 5.3.1 shows the team gluing one of the posters to a board.

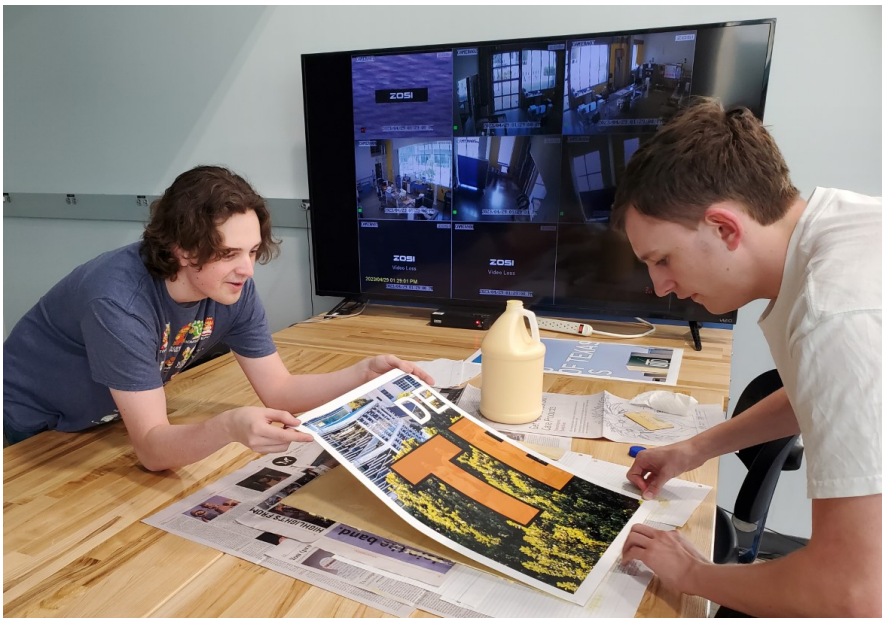

Fig 5.3.1: Application of Adhesive

5.4 - Engraving and Cutting

Prior to cutting any of the puzzles, the back of each board was engraved with the corresponding year (see section 5.1). Once this was complete, each board was cut using the

corresponding CAD file. Each file contained a unique puzzle, to further avoid any confusion during assembly. After each cut was complete, the pieces were then individually removed and sanded, if necessary. Each puzzle was then reassembled, to ensure that no pieces had been damaged or had gone missing. Fig. 5.4.1 shows an example of one of the assembled puzzles.

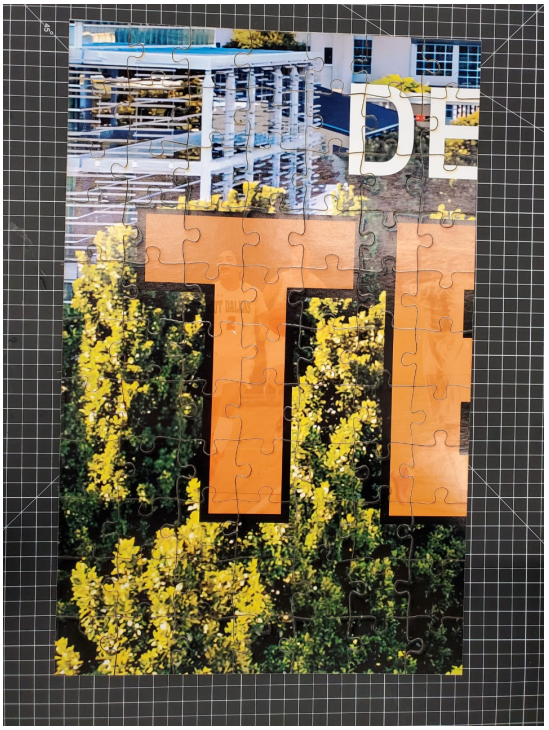

Fig. 5.4.1: Assembled Puzzle

Once all ten puzzles had been engraved and cut, they were all assembled and laid side-by-side in the correct positions and orientations.

5.5 - Extensions

Along with the ten puzzles and mapping key, the team also assembled a frame to house the puzzle. The frame was constructed with interior dimensions of 71”×45” to allow tolerance for both assembly and disassembly of the puzzle while within the frame. The frame was also constructed of wood and given the requirement of having to be transportable via an airplane. For this reason, the team decided to go with a peg and slot frame design similar to a mortise and tenon joint design (Fig. 5.5.1). Each end of the frame was given two holes: one hole with a peg glued into and the other to act as the female end for the adjoining frame piece. The frame was painted black for aesthetic purposes.

Fig. 5.5.1: Mid-Assembly Photo of the Frame

Along with the frame, the team also built a wooden GoPro mount, to allow for a timelapse video of the assembly to be taken at ICED. (Fig. 5.5.2)

Fig. 5.5.2: Painting the Mount

Fig. 5.5.3 shows the complete assembly, including the frame.

Fig. 5.5.3: Final Setup, Including Frame and Mount

5.6 - Summary

The ten puzzles (individually bagged), mapping keys, frame, and camera stand were placed in ECSW 1.160A, ready for pickup by Dr. Summers and travel to Bordeaux. All requirements (see section 3) had been met.

6) Acknowledgments

The team would like to express their gratitude to Dr. Joshua Summers for the invitation to work on this project, continued support, and helpful advice throughout.

Thanks is also due to Lois Alvar, UTD ‘26, whose conceptual graphic design proved invaluable to the final aesthetics of the puzzle.

This project could not have been completed without the help of Dr. Dani Fadda and Ms. Yi Tian, who generously made their workshops and equipment available to the team and were always available to give practical advice.

1. *UTD Wallpapers: https://alumni.utdallas.edu/wallpapers*
2. *Online Puzzle Generator: https://puzzle.telegnom.org/*