Decomposition-based assembly synthesis of automotive body structures

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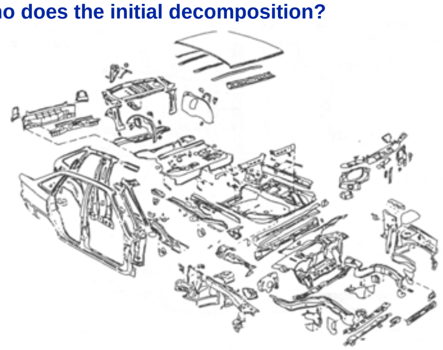
Outline

- **Introduction**
- **Related work**
- **Assembly synthesis**
- **Case study**
- **Summary**
- **Highlights of related projects**
- **Closure**

Introduction

- **Who does the initial decomposition?**



Source: American Iron and Steel Institute

Introduction

- **Decomposition determines**
  - Joint locations
  - Component geometry
- **Decomposition affects**
  - Structural stiffness (joints are less stiff).
  - Production cost (component manufacturing and assembly).
  - Design team organization
- **Decomposition needs**
  - “do it right for the first time” (redoing costs $$).

think carefully before decompose…

Introduction

- **Aluminum space frame (ASF) automotive bodies**
  - "Next generation" body structure
  - Extruded frames & cast parts joint by laser welding
  - Stiffer and lighter
  - Easier to design
  - High cost

Related work

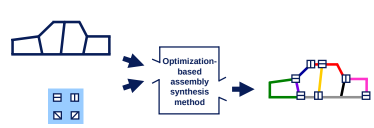
- **Design for assembly**
  - Boothroyd and Dewhurst (1983).
  - Gupta et al (1994).
- **Structural optimization**
  - Many, many….
- **Joint modeling**
  - Chang (1974); Garro and Vullo (1986); Lee and Nikolaidis (1992); Kim, Kim, Kim and Kim (2002).
- **Assembly synthesis**
  - Wang and Borne (1997)
  - Saitou and Yetis (2000); Yetis and Saitou (2000)

Related work

- **Where we stand**
  - Synthesis of assembly, not a modification of existing assembly.
  - Structural products.
  - Effects of joints on structural performance.
  - Insights, not the solution, to designers.

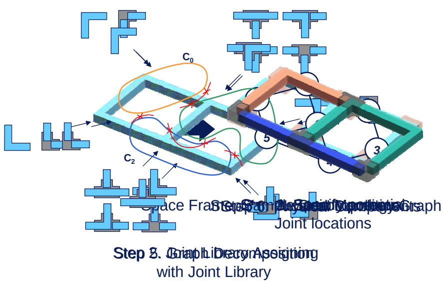
Assembly synthesis method

- **Given:**
  - Geometry of entire space frame structure and Joint Library
- **Find:**
  - Locations joints & cross-sectional dimensions of joined frames
- **Maximizing:**
  - Stiffness of assembled structure
  - Manufacturability
  - Assemblability



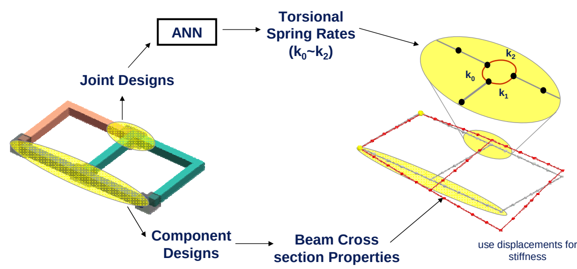
Assembly synthesis method

- **Overview**



Assembly synthesis method

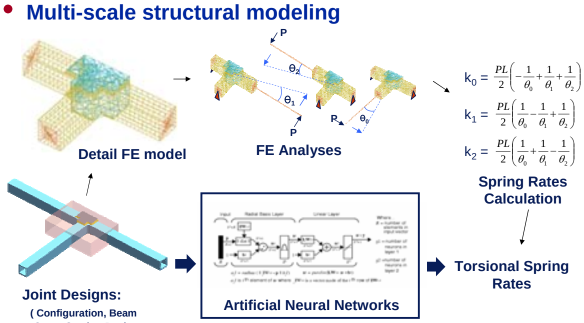
- **Multi-scale structural modeling**



FE model with Beam/Spring Elements

Assembly synthesis method

- **Multi-scale structural modeling**



$$k_0 = \frac{PL}{2}\left(-\frac{1}{\theta_0}+\frac{1}{\theta_1}+\frac{1}{\theta_2}\right)$$

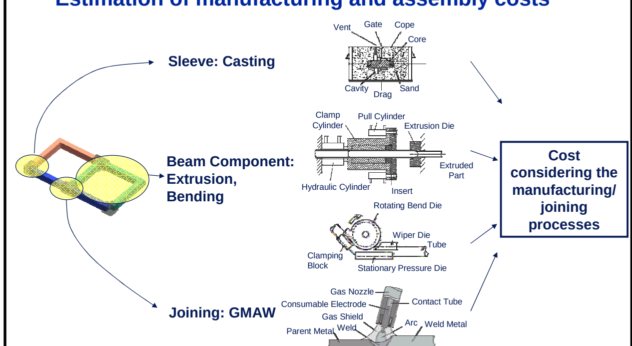
$$k_1 = \frac{PL}{2}\left(\frac{1}{\theta_0}-\frac{1}{\theta_1}+\frac{1}{\theta_2}\right)$$

$$k_2 = \frac{PL}{2}\left(\frac{1}{\theta_0}+\frac{1}{\theta_1}-\frac{1}{\theta_2}\right)$$

Reduce overhead during the main optimization

Assembly synthesis method

- **Estimation of manufacturing and assembly costs**



Assembly synthesis method

- **Design variables:**

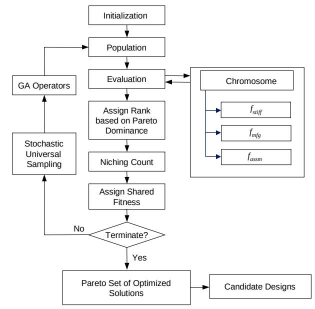
$$\boldsymbol{x} \in J_0 \times J_1 \times \cdots \times J_n \quad \text{Joint Library Vector}$$
$$\boldsymbol{y} \in S^B \quad \text{Beam Cross Section Vector}$$
$$\boldsymbol{z} \in W^n \quad \text{Weld Parameter Vector}$$

- **Objective functions (to be minimized):**

$$f_{stiff}(\boldsymbol{x},\boldsymbol{y},\boldsymbol{z}) = -\mathrm{DISP}(\mathrm{XSEC}(\boldsymbol{x},\boldsymbol{y}),\mathrm{JRATE}(\mathrm{XSEC}(\boldsymbol{x},\boldsymbol{y}),\boldsymbol{z}))$$
$$f_{mfg}(\boldsymbol{x},\boldsymbol{y}) = -\sum_{i=0}^{n-1}\{\mathrm{DIEC}(\mathrm{COMP}(i,\boldsymbol{x}),\boldsymbol{y}) + \mathrm{BNDC}(\mathrm{COMP}(i,\boldsymbol{x}))\} - \sum_{i=0}^{m-1}\mathrm{CASTC}(i,\boldsymbol{x})$$
$$f_{assm}(\boldsymbol{z}) = -C_w\sum_{i=0}^{m-1}\mathrm{WLDL}(i,\boldsymbol{z}) \times \mathrm{WLDT}(i,\boldsymbol{z})$$

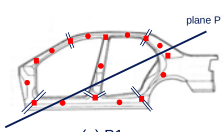
Assembly synthesis method

- **Multi-objective Genetic Algorithms (NSGA-II)**

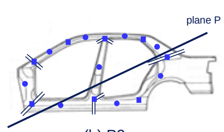


Assembly synthesis method

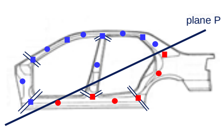
- **"Direct" crossover**



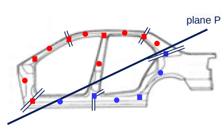
(a) P1



(b) P2



(c) C1

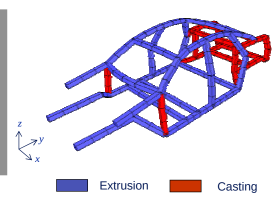


(d) C2

Case study

- **Automotive aluminum space frame (ASF) body**

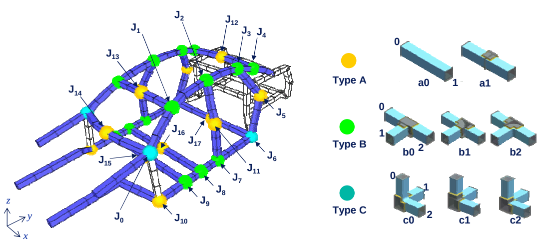
ASF Model



Simplified Frame Model

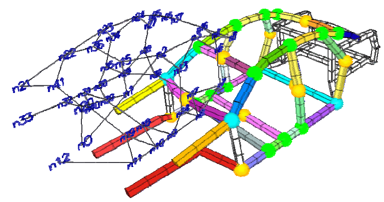
Case study

- **Potential joint locations and Joint Library**



Case study

- **Basic members and structural topology graph**



Basic Members Topology Graph

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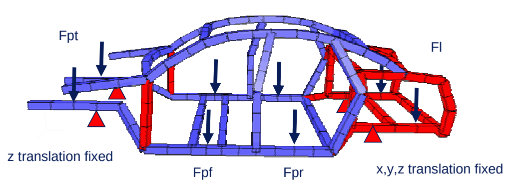
Case study

- **Global bending loading condition**



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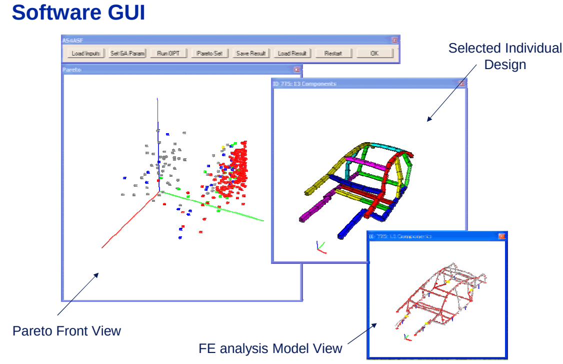
Case study

- **Software GUI**



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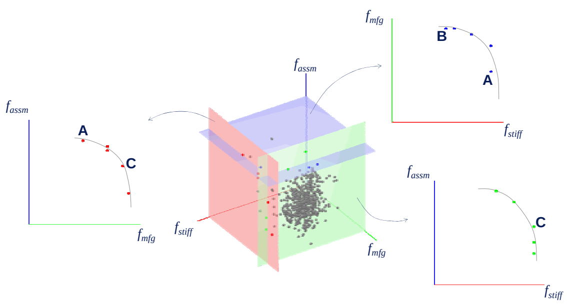
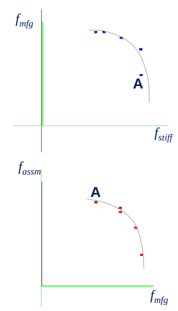
Case study

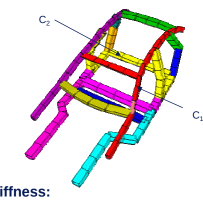
- Pareto Front at generation = 100, population = 1000



Case study

- Sample design A



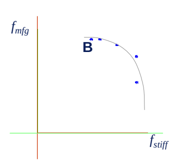


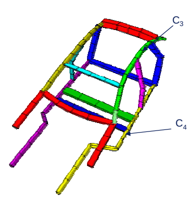
Good stiffness:
- Long one piece Roof Rail (C_1)
- 3D geometry Rear Cabin Comp. (C_2).

Poor manufacturing cost:
- Large number of components (14)
- Complex Comp. with bends (C_2)

Case study

- Sample design B



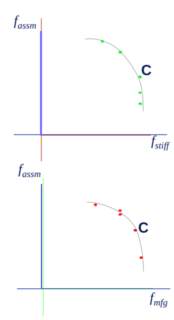


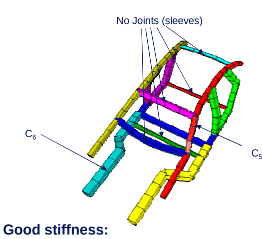
Good manufacturing cost:
- Minimum number of components (12)
- Relatively Straight Comp. (C_3 & C_4)

Poor stiffness:
- Thin-walled comp. (C_3 & C_4)

Case study

- Sample design C





Good stiffness:
- Long one piece Roof Rail (C_5)
- Thick Comp. in the Rocker (C_6).

Good assembly cost:
- Minimize the number of Sleeves (14)

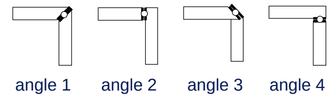
Good manufacturing cost:
- Straight comp. (C_5)

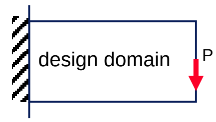
Summary

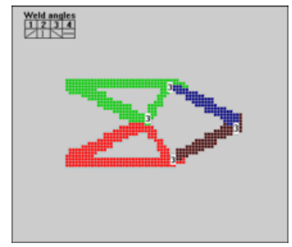
- **Summary**
  - Multi-component structural assembly synthesis of AFS using Joint Library
  - Multi-scale structural model
  - Multi-objective optimization maximizing structural stiffness, manufacturability and assemblability
- **For more details:**
  - Lyu, N., and Saitou, K., 2004, “Decomposition-based Assembly Synthesis of Space Frame Structures using Joint Library,” Proceedings of the *2004 ASME Design Engineering Technical Conferences*, Salt Lake City, Utah, September 28 - October 2, 2004, DETC2004-57301.

Highlights of related projects

- **AS for strength**
  - Student: Arkin Yetis

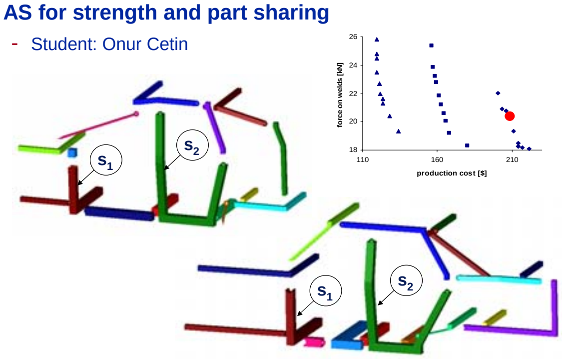






Highlights of related projects

- **AS for strength and part sharing**
  - Student: Onur Cetin

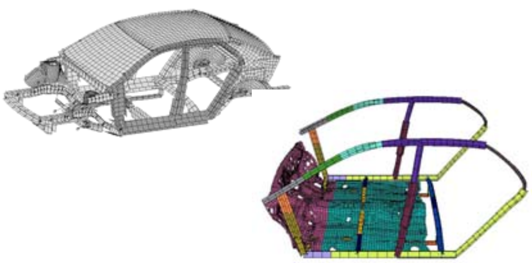


Highlights of related projects

- **Publications**
  - Yetis, A. and Saitou, K., 2002, “Decomposition-Based Assembly Synthesis Based on Structural Considerations,” *ASME Journal of Mechanical Design*, v. 124, p. 593–601.
  - Cetin, O. and Saitou, K., 2001, "Decomposition-based Assembly Synthesis for Maximum Structural Strength and Modularity," Proceedings of the *2001 ASME Design Engineering Technical Conferences*, Pittsburgh, Pennsylvania, September 9–12, DETC2001/DAC-21121. Also in print as Cetin, O. L. and Saitou, K., "Decomposition-based Assembly Synthesis for Maximum Structural Strength and Modularity," *Transactions of ASME, Journal of Mechanical Design.*
  - Cetin, O., Saitou, K., "Decomposition-Based Assembly Synthesis for Structural Modularity," *Transactions of ASME, Journal of Mechanical Design,* in print.
  - Cetin, O and Saitou, K., 2003, "Decomposition-based assembly synthesis of multiple structures for minimum production cost" Proceedings of the *2003 ASME International Mechanical Engineering Congress and R&D Expo*, Washington, D.C., November 16 - 21, IMECE2003-43085. Also in print as Cetin, O and Saitou, K., "Decomposition-based assembly synthesis of multiple structures for minimum production cost," *Transactions of ASME, Journal of Mechanical Design.*

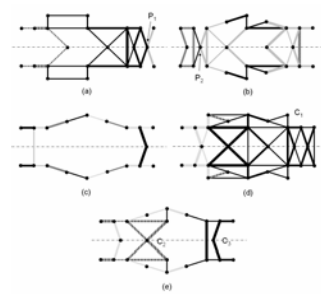
Highlights of related projects

- **AS of beam-panel FE models**
  - Student: Naesung Lyu



Highlights of related projects

- **Multi-component structural topology design**
  - Student: Naesung Lyu

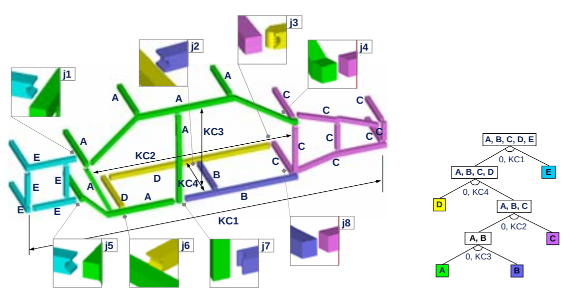


Highlights of related projects

- **Publications**
  - Lyu, N. and Saitou, K., 2003, "Decomposition-Based Assembly Synthesis for Structural Stiffness," *Transactions of ASME, Journal of Mechanical Design*, vol. 125, pp. 452-463.
  - Lyu, N and Saitou, K., 2003, "Decomposition-Based Assembly Synthesis of a 3D BIW Model for Structural Stiffness" Proceedings of the *2003 ASME International Mechanical Engineering Congress and R&D Expo*, Washington, D.C., November 16 - 21, IMECE2003-43130. Also in print as Lyu, N and Saitou, K., "Decomposition-Based Assembly Synthesis of a 3D BIW Model for Structural Stiffness," *Transactions of ASME, Journal of Mechanical Design.*
  - Lyu, N. and Saitou, K., 2003, " Topology Optimization of Multi-Component Structures via Decomposition-Based Assembly Synthesis," Proceedings of the *2003 ASME Design Engineering Technical Conferences,* Chicago, Illinois, September 2-6, DETC2003/DAC-48730. Also in print as Lyu, N. and Saitou, K., "Topology Optimization of Multi-Component Structures via Decomposition-Based Assembly Synthesis," *Transactions of ASME, Journal of Mechanical Design.*

Highlights of related projects

- **AS for in-process dimensional adjustability**
  - Student: Byungwoo Lee



Highlights of related projects

- **Publications**
  - Lee, B. and Saitou, K., 2003, "Decomposition-based Assembly Synthesis for In-Process Dimensional Adjustability," *Transactions of ASME, Journal of Mechanical Design,* vol. 125, pp. 464-473.
  - Lee, B. and Saitou, K., 2003, " Assembly Synthesis with Subassembly Partitioning for Optimal In-Process Dimensional Adjustability," Proceedings of the *2003 ASME Design Engineering Technical Conferences*, Chicago, Illinois, September 2-6, DETC2003/DAC-48729.
  - Lee, B. and Saitou, K., 2004, "Three-dimensional assembly synthesis for robust dimensional integrity based on Screw theory," Proceedings of the *Fifth International Symposium on Tools and Methods of Competitive Engineering*, Lausanne, Switzerland, April 13 - 17, p. 585-596 (Best Paper Award).
  - Lee, B., and Saitou, K., 2004, "Integrated Synthesis of Assembly and Fixture Scheme for Properly Constrained Assembly," Proceedings of the *2004 ASME Design Engineering Technical Conferences*, Salt Lake City, Utah, September 28 - October 2, 2004, accepted.

Acknowledgement

- **"Powered" by…**

National Science Foundation

CAREER Award:
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TOYOTA

Closure

- **For more information:**
  - http://www-personal.engin.umich.edu/~kazu/publications.htm
  - kazu@umich.edu