Literature Survey

For Interlocker

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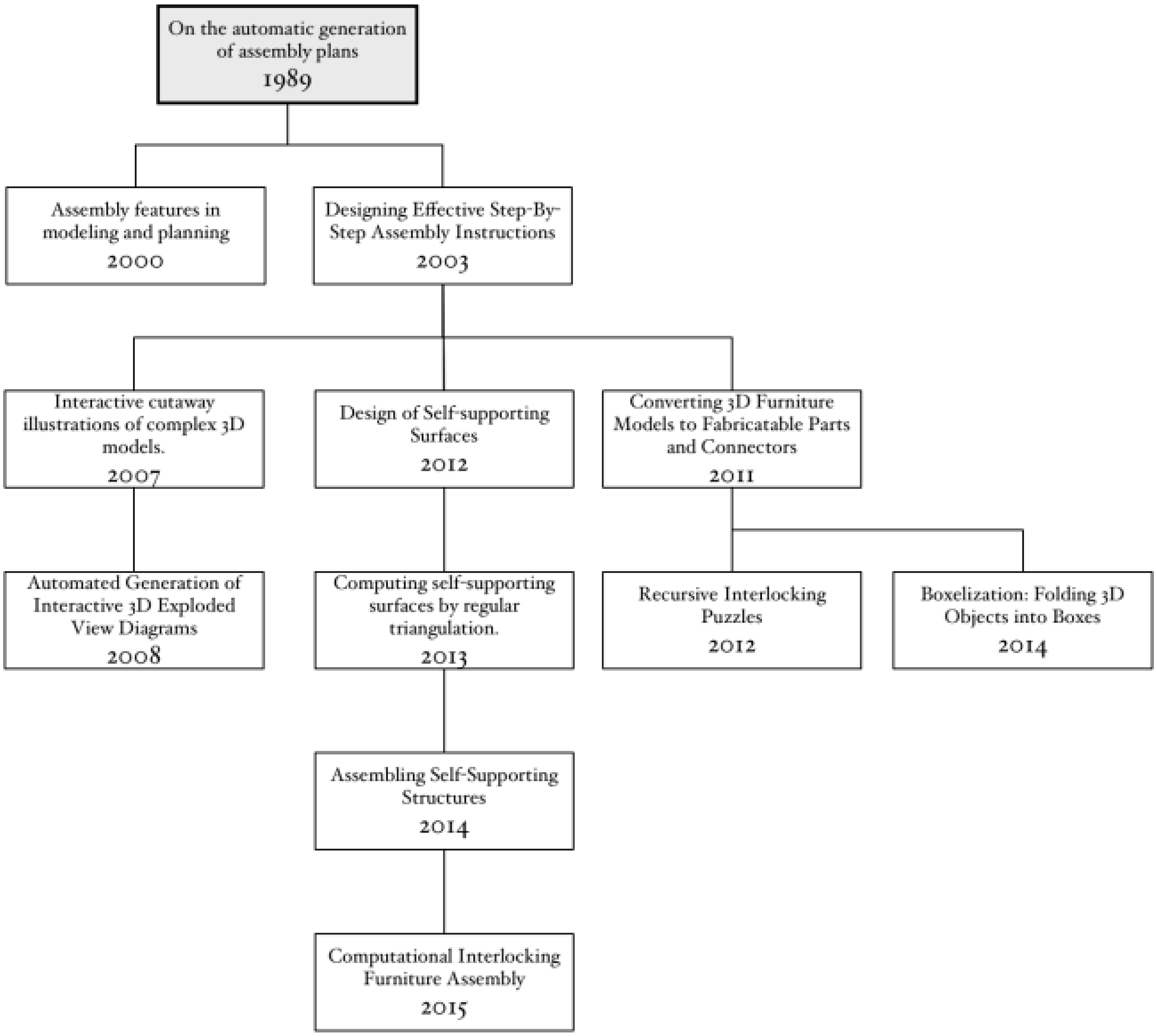
Introduction

Different parts of traditional furniture are usually connected with glue, nails, hinges, screws, etc. However, connecting parts of furniture this way makes it hard to take apart the pieces again since common connectors do not encourage furniture disassembly and reassembly, and often harm the external appearance of the furniture and generally the principles of the design. Interlocking furniture encourages assembly and disassembly and allows the components to be tightly interlocked with one another. Interlocking furniture becomes challenging when dealing with complex furniture which include many different components and requires a great deal of exploration to achieve global interlocking.

Our authoring tool, **Interlocker**, is based on the paper, **Computational Interlocking Furniture Assembly [FSYYJC15]**, and is intended for an application which takes a furniture design consisting of just a set of simple 3D parts (e.g., rectangular boxes) as input, and outputs a modification of the 3D parts with appropriate joint geometry that interlocks the component parts.

In this literature survey, we trace from the seminal paper **[W89]**, through papers which discuss 3D fabrication, fabrication by parts, 3D interlocking assembly, fabrication of self-supporting structures, till the interlocking furniture assembly paper our authoring tool is based on.

Content:


On the automatic generation of assembly plans
1989
Assembly features in modeling and planning
2000
Designing Effective Step-By-Step Assembly Instructions
2003
Interactive cutaway illustrations of complex 3D models.
2007
Design of Self-supporting Surfaces
2012
Converting 3D Furniture Models to Fabricatable Parts and Connectors
2011
Automated Generation of Interactive 3D Exploded View Diagrams
2008
Computing self-supporting surfaces by regular triangulation.
2013
Recursive Interlocking Puzzles
2012
Boxelization: Folding 3D Objects into Boxes
2014
Assembling Self-Supporting Structures
2014
Computational Interlocking Furniture Assembly
2015

[W89] In the seminal paper, the author introduces an experimental assembly planning system which is capable of generating swift plans for most assemblies. To be able to solve this problem, the system must be capable of reasoning about a large collection of part insertion trajectories and must of course be capable of optimization when it comes to complex, application-dependent criteria. The author proposes to solve the assembly planning problem in the three stages. In stage 1, a set of insertion trajectories are proposed which are likely to be useful. In stage 2, geometric constraints are constructed, where the parts of every proposed trajectory are checked to see if they block the trajectory if they were already in their final positions. And finally, in stage 3, a trajectory is selected for each part and they are ordered such that none of the constraints are violated. The work presented here by the authors is then evolved in **[HB00]** and **[APHHKHT03]**, where the authors look into more detail on assembly features in modeling and planning and how to design effective step-by-step assembly instructions.

[HB00] This paper proposes an integrated object-oriented product model for modeling and planning of both single parts and assemblies. A prototype modeling environment was developed and has been verified in many analyses and planning modules, specifically stability analyses, grip planning, motion planning and assembly sequence planning. The authors state that using feature-based product models for assembly will definitely help in assembly modeling and planning by integrating single-part and assembly modeling, and by also integrating modeling and planning.

[APHHKHT03] The other paper which stems from the seminal paper **[W89]**, is where most of the future work related to our authoring tool paper comes from. In this paper, the authors present design principles for creating effective assembly instructions and a system that is based on these principles. The principles are drawn from cognitive psychology research which investigated people's conceptual models of assembly and effective methods to visually communicate assembly information. The paper's proposal is then used in three papers, **[LRACS07]**, **[LOMI11]** and **[VHWP12]**. The paper **[LRACS07]** discusses cutaway illustrations of complex 3D models. **[LOMI11]** converts 3D furniture models to part and connectors which can be fabricated. And finally, **[VHWP12]** looks into the design of self-supporting surfaces.

[LRACS07] The paper presents a system for authoring and viewing interactive cutaway illustrations of complex 3D models using conventions of traditional scientific and technical illustration. It is based on the two key ideas that cuts should respect the geometry of the parts being cut and that cutaway illustrations should support interactive exploration. The interactive cutaway ideas presented in this paper are then used with 3D models that can be organized into an exploded graph in **[LACS08]**.

[LACS08] Following from **[LRACS07]**, this paper introduces an automatic technique for organizing 3D models into layers of an explosion graph that shows how parts explode with respect to each other. The explosion graph also handles the most common classes of interlocking parts. It also introduces two algorithms for exposing user-selected target parts, one that explodes the necessary portions of the model in order to make the targets visible, and another that combines explosions with the dynamic cutaway ideas presented in **[LRACS07]**.

[LOMI11] The other paper inspired by **[APHHKHT03]**, solves the problem of taking an inputted 3D model of a man-made object, and automatically generating the parts and connectors required to build the corresponding physical object. The paper focuses on furniture models and the defining of formal grammars for IKEA cabinets and tables. Lexical analysis is also performed to identify the primitive parts of the 3D model. It is then followed by a structural analysis that gives structural information to these parts, and generates the connectors (i.e. nails, screws) needed to attach the parts together. The work presented in this paper is used in two papers, **[SFC12]** and **[ZSMS14]**, providing solutions to recursive interlocking puzzles and the folding of 3D objects into boxes respectively.

[SFC12] Here, the authors introduce a formal method for interlocking mechanics to develop a constructive approach for designing new recursive interlocking geometries that directly ensures the validity of the interlocking instead of exhaustively testing it. The authors define recursive puzzles are those where which the assembly of puzzle pieces can be an interlocking puzzle also after sequential removal of pieces. With such puzzles, there is only a single sequence for assembling/disassembling them. The authors proposed method allows efficient generation of recursive interlocking complex geometries, which can be applied to LEGO bricks to allow the hand-built formation of puzzle games.

[ZSMS14] In the second paper, proceeding from **[LOMI11]**, the authors introduce a technique for transforming a 3D object into a cube or a box using a continuous folding sequence. The method suggested produces a single, connected object that can be physically fabricated and folded from one shape to the other. This is done by splitting the 3D object into voxels and then look for a voxel-tree which can fold from the input shape to the target shape. The method can be carried out in three main steps. The first step is to find a good voxelization. The second step is to find a tree structure that can form the input and target shapes' configurations. And finally, the last step is to find a non-intersecting folding sequence.

[VHWP12] In this third paper that branches from **[APHHKHT03]**, the authors use an analysis method called the thrust network to create an iterative nonlinear optimization algorithm for approximating freeform shapes by self-supporting ones efficiently.
The nature of the thrust networks geometry allows the algorithm to close connections between diverse topics in discrete differential geometry. The idea of self-supporting surfaces in general is used in many papers which are either referenced by or relevant to our authoring tool paper. These papers include the current paper in discussion, [**LHSWG13]** and **[DPWLBSP14]** which are all directly referenced in our authoring tool paper **[FSYYJC15]**.
[LHSWG13] Following from **[VHWP12]**, the authors of this paper focus on the designing of surfaces of masonry structures because such structures have to be compressively self-supporting. They state that a surjective mapping exists between a power diagram, defined by a set of 2D vertices and associated weights, and the reciprocal diagram that characterizes the force diagram of a discrete self-supporting network. From this

information, the authors define a new and convenient parameterization for the space of self-supporting networks and propose new method for geometry processing which include surface smoothing and remeshing. The work shown here is then evolved in the paper **[DPWLBSP14]** which presents an efficient construction method for masonry structures.

[DPWLBSP14] This paper builds from the research in the creation and exploration of self-supporting freeform designs where the authors recognize the difficulty in constructing such structures which need extensive formwork during assembly that leads to high construction costs on a building scale. The authors propose a gradual construction method of the masonry model in stable sections which drastically reduce the material requirements and construction costs. The method is then checked on 3D printed models. Also, examples of the application of the method is shown through the restoration of historical models and also designs of self-supporting puzzles are explored.

[FSYYJC15] Based on many of the papers summarized above, this paper introduces a computational solution which allows the design of large networks of globally-interlocked furniture. To achieve this goal, a novel computational solution is developed with the following key ideas. First, we formulate a formal model to define global interlocking, which is based on the converting concept in **[LOMI11]**. It is a group-based interlocking scheme backed up by a mathematical proof, while the scheme itself is evolved from the Interactive Cutaway Illustrations in **[LRACS07]**. Using this model, an overlapping set of small interlocking groups can be constructed over the furniture complex, where the parts in each group are locked by a local key, and adjacent groups are further locked with dependencies. As a result, global interlocking can be achieved over all the parts with only a single mobile key, and this saves the enormous effort of exploring the immobilization of every subset of parts in the assembly. To put this model into practice, connections between adjacent parts are analyzed to determine possible joint geometries that could be deployed at each connection. An iterative method can then be developed to construct small interlocking groups by assigning appropriate local joints, and progressively achieve global interlocking by further creating dependency between adjacent groups. By this means, appropriate joint geometry can be created between adjacent parts to produce an interlocking furniture assembly. In terms of the design of self-supporting structures, just like inter-locking furniture, it requires a global analysis of all the components which can be found in **[VHWP12]**.

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