DRAFT Date:
October 1, 2025

ETID Department
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What This Guide Covers

This is a design guide in memo format which will receive many iterations. After a decade of practice, it is now appropriate to cover the most common aspects that recur in the open source design collection I've titled "openlab project"

- Design for manufacturing
- Design for FDM printing
- Design for open publication
- Design for off-the-shelf integration
- Compliant mechanisms
- Design of assemblies
- Functional Parts Design

Among the listed topics, there lies many conflicts between one goal and another goal. And there are many optimal choices that satisfy multiple needs at once. From my decade of design under the listed conditions, I created routines that usually satisfy all the necessary needs to make functional parts, and found consistent choices that can make repeatable parts. Now the set of rules and guidelines are becoming apparent enough to write down along with their reasons and limitations.

Definitions

Understanding a model: to gain the level of study on a model such that one can rebuild the model from scratch, and one can modify a model with the full readiness as the original author.
Pinned joint: a joint not only implementing a pin but also having greater contact between pin and inner diameter than the contact between jointed faces. discussed as a subcategory, in friction joints.
Complicating a model is to add features, add dimensions, or data which could still be removed while maintaining the design intent.
Ready or Readiness is a binary criteria summarized by the quality and completeness of this part is sufficient to post.

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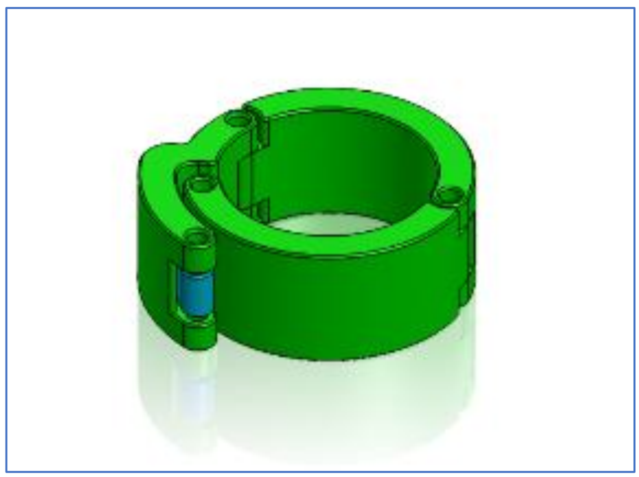
If the part is ready, then the open source collaborators have power to A) gain the utility and B) improve the model.
Worry: to perform engineering effort aimed to countermeasure and undefined or unvalidated problem.
Post: A publicly accessible repository of a model of a design, such as a GrabCAD upload. The post can be differentiated by its hyperlink, or by its' author and post title.

Examples

The Examples section I am using to express a broad range of concepts, which map to a consistent set of rules. As of 2025 september I have not recorded rules so this list will help formulate them.

Compression of parts

The following compression part has deviations that can stack up so it is better to separate the compression target from the design geometry.

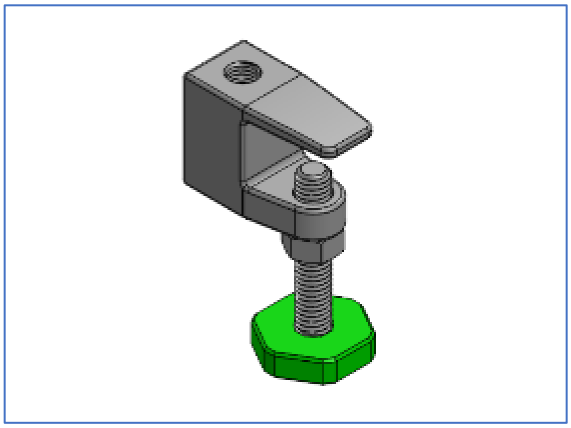


For this part called "collar" the diameter in the design would simply be made as a clearance size around the tube to be compressed. Then, a separate component such as a thin film of rubber or cork sheet would be applied.

We can deboss a region to consume part of the thickness of the cork, so 6mm cork may sit in a 5mm deboss and we target 1mm of compression.

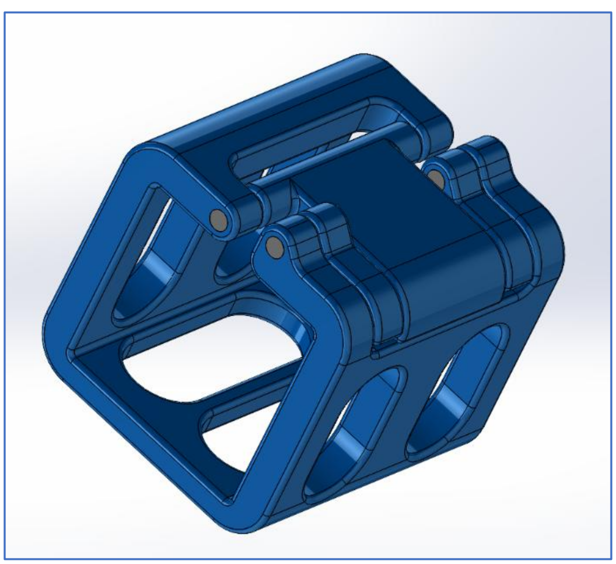
Constrain and then bond

This example shows a knob item added to the head of a machine screw. The (need picture) mating surfaces constrain the green part WRT the bolt in all directions before we add an adhesive. This means the adhesive is not to battle forces, only to hold the parts from slipping.



Compliance as a Linkage

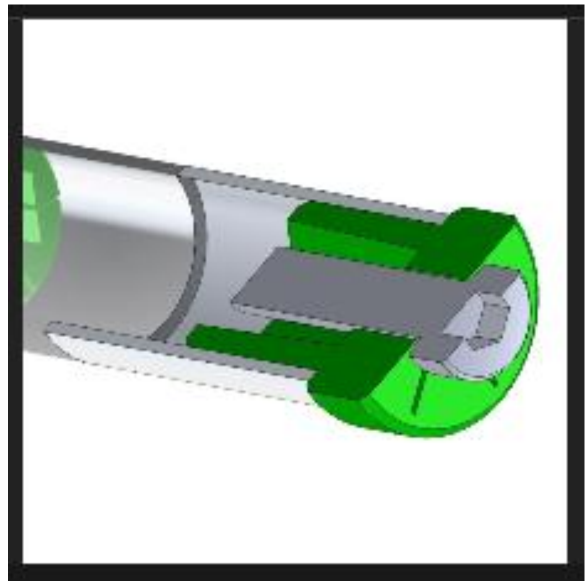
This is an example of merging a four-bar-linkage design and compliant design. The linkage function is only to move the assembly a small distance so then one solid member can tolerate the movement of opening and closing and remain in the elastic region of deformation.



Limited Compliance, Compression

This part titled mandrel creates a high stress on the ABS plastic but only in compression. The squeezing of the internal nut (not shown) against the plastic pushes it against the steel wall. It is a general rule not to make a high stress state of the polymer a direct function of the part, but in this case we know we are only compressing the plastic.

We limit the maximum possible compressive stress due to the difference between the tube inner diameter and the thickness of the plastic at the thickest region of the taper.



Curling Relief

Flat planes resting on the printer bed are under stress due to the steep temperature gradient in the vertical direction. The bed is hot (below) and the next layers are cool (above). This stress can be relieved by segmenting the part between areas of the base layer.

Version Numbers

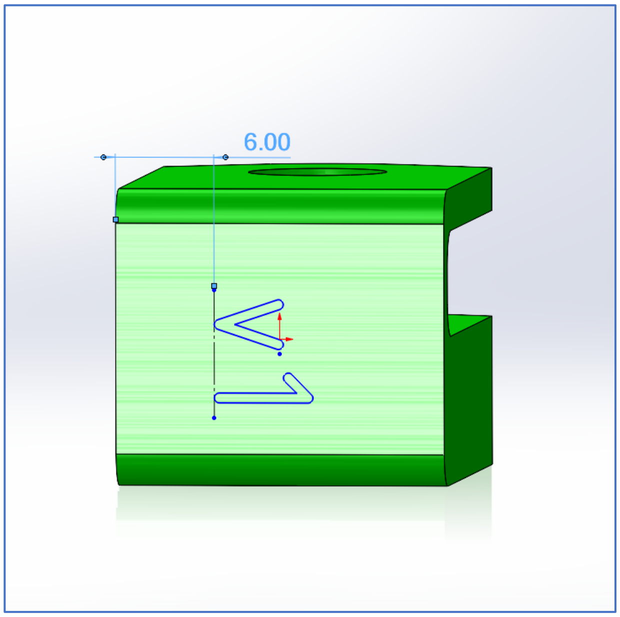
(version numbers have several layers of meaning and rules which are broken frequently so the ideal scenario is listed here).
The version number answers “how many changes have been made which actually drove a print-fit-use cycle?” This means if the part is adjusted in the model and not printed, the version has not changed. If the part was printed, and immediately failed to fit in the assembly, the part has not been used yet and remains at version 1. If the part is used, then received an improvement with no change in function, and reprinted, we have a version 2.

Version numbers are most important when distributing data. If the part is sent by email, posted online, or in some manner “receiving a timestamp in real life” then it ought to also have a unique version number, and that unique version number ought to reflect what is found elsewhere online with a matching version.

Version numbers are added to the part with a deboss and oriented in a way that communicates the "upright" printing direction. Desbossed versions contain:

- 6mm height of text
- DS ISO Bold font
- 6mm height from base of the part
- 0.5mm depth of deboss

The text in solidworks resides on a construction line, on a location that will be visible when assembled, ideally on a flat location of the part where additional space is available for text.



Design Orientation:

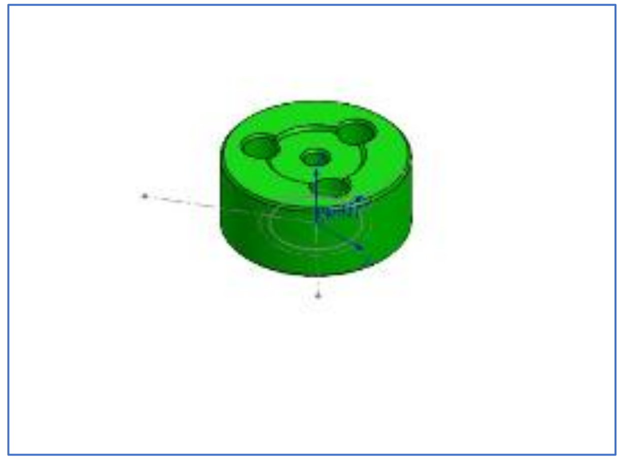
Print settings and Design

Print settings must not feedback information back to the design desk! We are validating a design which carries intention of "printing on FDM with ABS" and if a part has failures then the failure should be either "failed print" or "failed design." We must be able to refine our designs and refine our printer separately.

Limited Lifetime of Use

The part called "holeGuide" functions in a similar way to a drilling guide commonly found at hardware stores. This part constrains a drill bit to perpendicularity with a wooden part. In a normal design rule set we cannot allow the plastic holes to rub tightly against a drill bit due to wear. The walls will gradually lose their dimensions causing loss of function. However this part is made for a use case only a fraction of typical use-count. It functions in the assembly stage of a specific assembly, so 10 uses will not cause failure.

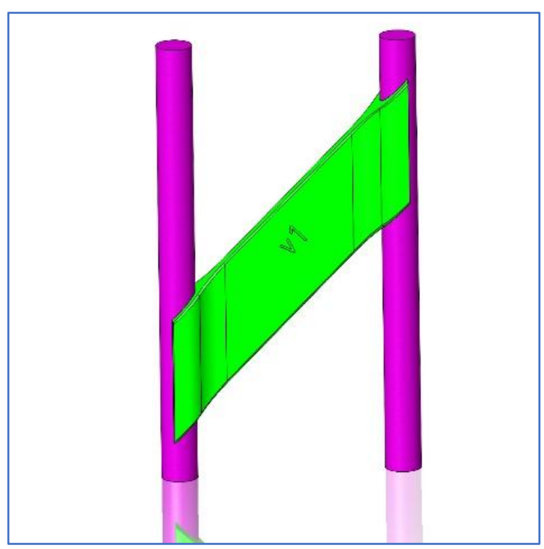
If we wish for the same part to have a permanent life then the hole diameters can be enlarged and fit with a brass or steel collar. Our global locations have high accuracy to satisfy the purpose of aligning a drill within 0.2mm global locations.



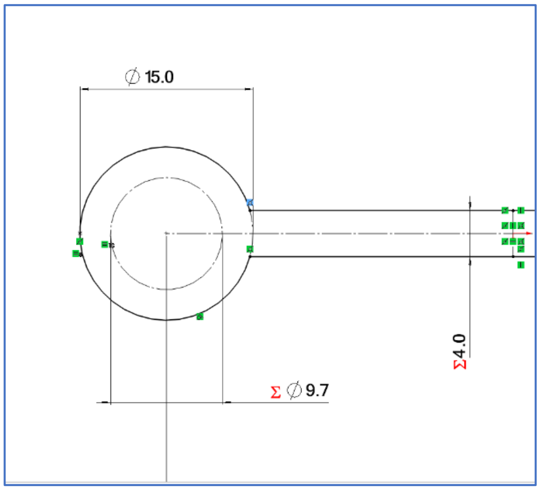
Clamping Round feature

The "web" part makes a snap-fit with two rods and re-uses a geometry for ABS plastic grasping the round stock successfully. The general rule is to take the hole diameter and use 70% of that diameter as the arms' reaching dimension.

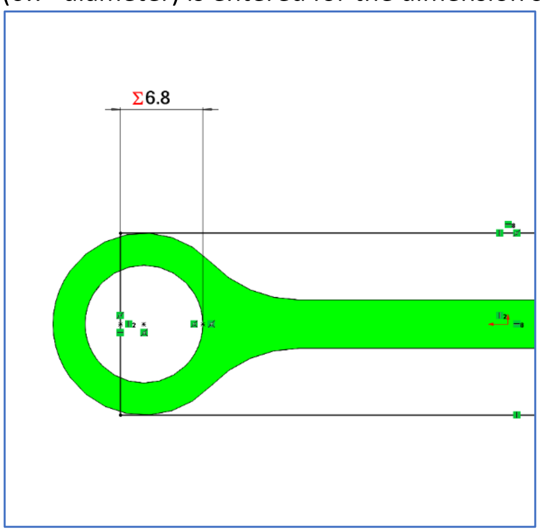
Once seated, the pole will have friction in the grip because diameters were matched (arms and pole) without any design gap. The print is estimated to require 0.6mm around a diameter for guaranteed slipping so we have eliminated 0.3mm at each side of the radius by matching diameters.



The sketch (next image) shows a designed hole diameter of 9.7mm which is the measured diameter of the rod with ordinary calipers.
The assumptions about fitness of a grip is based on the extruded material in the x-y plane.

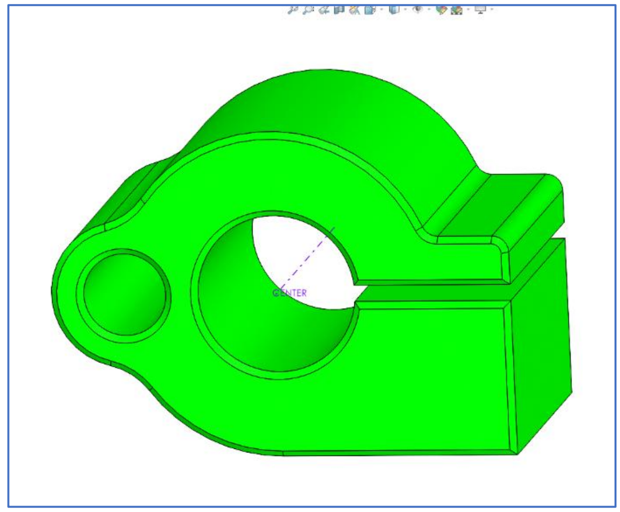


First the model is built such that the whole circumference is contacted, then the material is trimmed from the end. The cut-extrude is made with the following sketch which shows a 6.8mm calculated distance where an equation (0.7*diameter) is entered for the dimension shown.



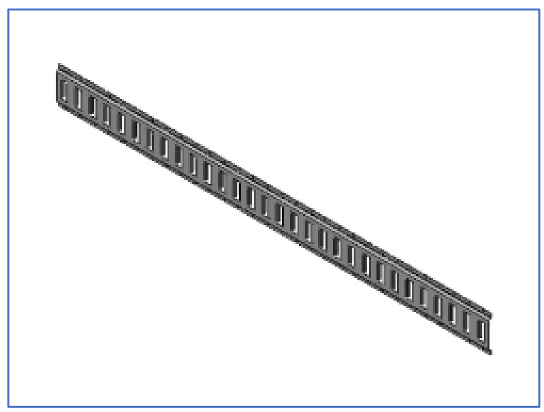
Gap, Pre-Clamping

This part, titled "clamp" is to be clamped on a round tube to carry load in multiple directions. The fastener (not shown) will tighten the ABS plastic around the large tube and then cause the gap to tighten. For this type of clamping I set the tube and clamp with equal diameters and then I leave a gap greater than 1mm to begin with. From many uses, parts like this made for a 30mm round bar, the 1mm gap will be closed or near-closed due to the tightening.



Center Datum

For long stock which will appear in various lengths in an assembly or in future designs, the cross-section is built on the RIGHT plane and the extrusion of length is made from the origin in both directions. There are benefits of extruding in one-direction but this choice has shown the most benefits for the most purposes later in the workflow.

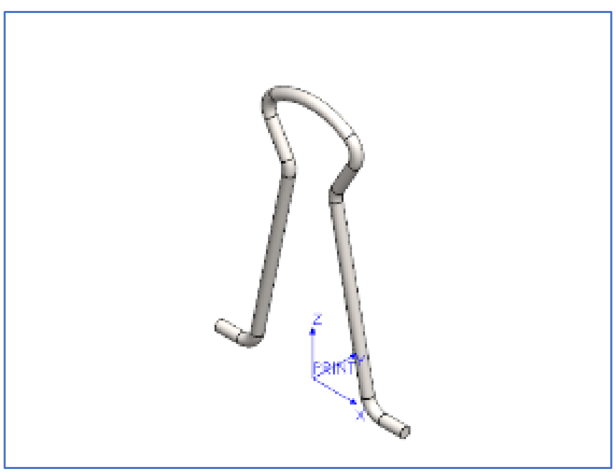


Fastener-floor

The floor where a fastener clamps down is set to 4mm to 6mm. This gives compatibility with our common screw lengths for M6 and M5, usually 10 or 12 mm. The floor is the region that rests below the fastener head and becomes compressed when the screw is tightened.

Springs

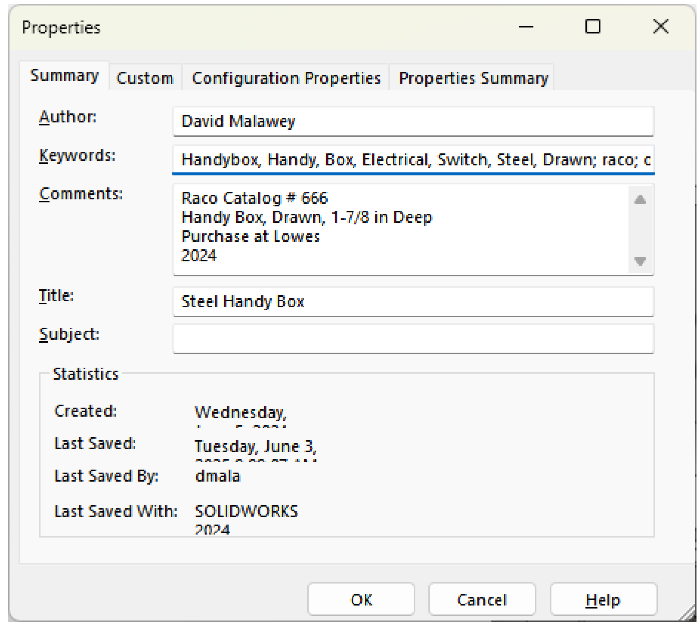
Spring-designated parts are always drawn in their natural form and the model is not enhanced with any simulations of deflection etc. This spares the work effort until the part is put into use. In some cases the working part is measured at key locations in a deflected state, and then a simple line or point added to the sketch indicating where deflection is desired to end. The part shown is called spring.sldprt



Standard Origins

A part which has its full geometry rooted in a public standard and which has it's dimensions rooted in real life-parts – this type of part is uniquely valuable for modeling and choosing a master configuration. For this type of model, we break all skill-based limitations in the modeling of this part because contributors have access to the true geometry. If I post a design which has shortcomings, those shortcomings can be corrected by a high volume of community designers, hugely boosting the chance of improvement. Therefore, the existence of the post becomes more important than the correctness of the model.

Handybox.sldprt is one of these parts which deserves high effort in modeling and planning. The



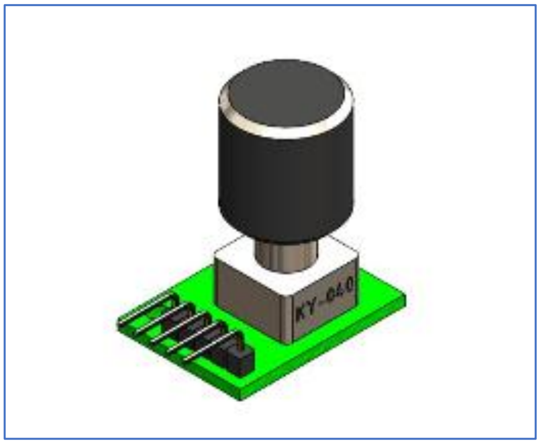
Circuit Board Abstraction

The circuit below features a rotary knob and like many boards it's nothing but a host for one key sensor and the terminals to connect it. The board is to be redesigned with 1) minimal features and 2) beginning with board dimensions, hole locations, the tallest feature, and the interface locations.

The interface locations are places where assembly-level design must offer clearance, or mate, or access for a tool. The features at interface locations are to be modeled.

The identifying features of the physical part are those which can be seen in a thumbnail image and are not required for functionality but are required for a "ready model."

A board made of an assembly which can be changed may have geometry of interest.



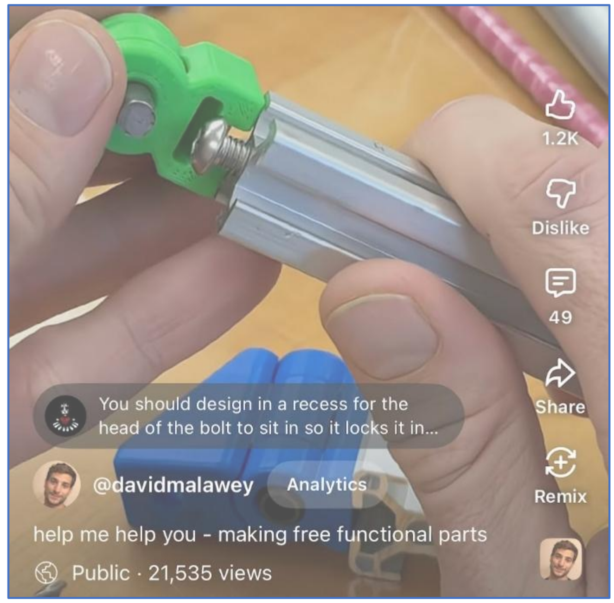
Worrying Not Permitted

Worrying: implementing a countermeasure for a failure mode which lacks validation through testing.

While designing a part, we should not add material thickening or geometry that makes the part “extra strong” on the first trial. If there is a concern for strength of a feature then produce the geometry that serves the function and then gather data about the limit of strength or other failure concern.

Worrying produces artifacts in a design which obscure the design intent & often carryover into revisions wherein the design focus is on another feature, so the unnecessary solution does not later become omitted from the design. It remains captive, potentially forever stacking up the added cost & material across iterations & space & time.

In the following image we have a design suggestion from a peer to add a feature to this joint part. The suggested feature is in the worry category if the “locking of the bolt head” is the solution while “slipping of the bolt head” is not a verified issue.



The impact on this particular part: This part has fairly complex model geometry such that it is challenging to understand. The average user is likely to copy the design without studying and understanding the model, which is no problem. In this case, the user is also not prepared to omit features, even unnecessary ones. Our goal is to publish the most simplified variation of the model. Then, users can worry more complexity into the model at their desk even though they can’t worry complexity out of the model.

Orphaned Functions

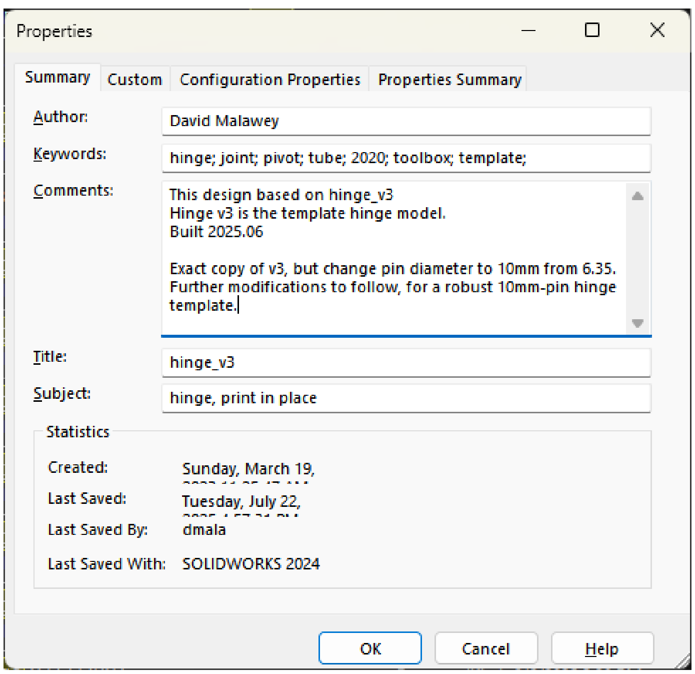
The joint part in the above photo has two functions, those are [fasten to the extrusion end] and [perform pivoting in one DOF]. The functions may individually appear in other parts. Firstly, the design should be simplified to execute one function instead of two. But such a change would break the total function of this application. In this case, each of those two functions should appear in a “representative part” that is designed separately, and features the highest level of refinement and simplification that can be made.

If we publish a part which carries a function but this function is in need of a representative part which isolates that function. Without a representative part, we have created an **orphaned function**. The representative part is the only way to direct the community designers towards improvements and allow re-integration in their own separate designs.

The following image depicts a reduced model of a hinge which retains the refined singular function so it is simply called Hinge V4.

For a representative part it becomes crucial to note that it is a "master model." This note should be included in the same directory as the model, or better yet, in the same document. For this Hinge_v4 I included information in the "comments" section shown below.

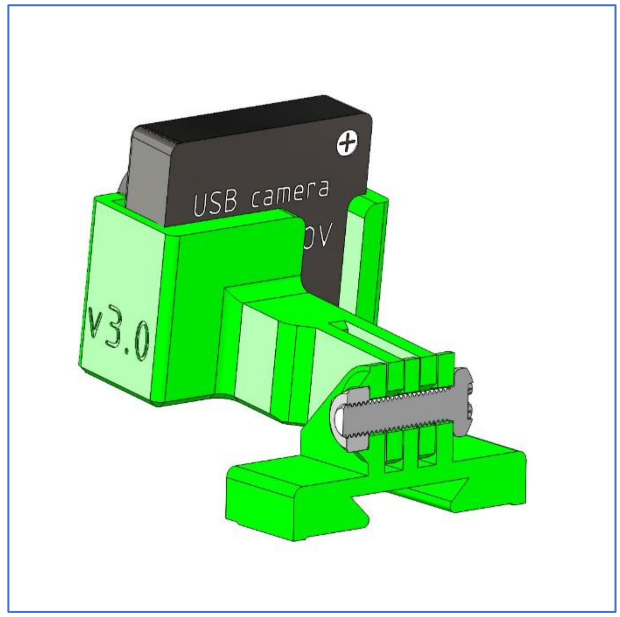
Without the comments, these representative parts multiply across the hard drive in many locations having matching keywords, and can cause the best pure model to become lost.



Friction Joints

A friction joint is a joint which has a freedom of movement with a desired minimum friction in such movement. **Fingers** in a friction joint are the two-dimensional protrusions in a cross-section of this joint which interlock with a pin.

For adding friction without adding clamping force, the number of fingers is increased. The friction increases by a multiple equal to the interface count, given the same clamping force. If the finger faces are to control the friction level of the joint, then a clamping force is a control mechanism, as shown in the camera pivot below.



Friction Joints, Pinned

A friction joint which carries more friction against a pin is called a pinned friction joint.

If the pin of the joint has threads, then the hole size is selected as **clearance** and the pin size is selected as nominal major diameter of the screw. For example, the M5 screw has 4.7mm major diameter and a 5.0mm nominal diameter and the clearance condition calls for 0.3mm diametric clearance so the designed hole size is 5.3mm.

Thin Wall Thickness

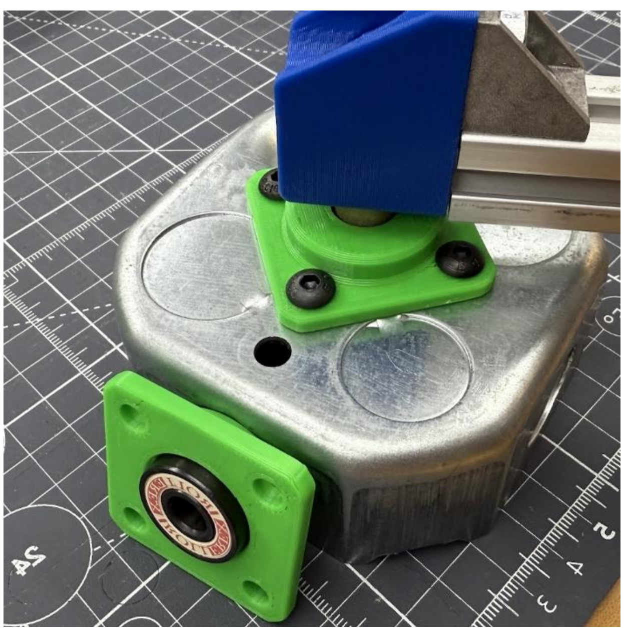
Thin walls are walls which serve their function by existing prior to any requirements for load. These are selected at 1.6mm minimum (this accommodates a debossed label at 0.5mm)

Wall thickness is minimized at the start of the design, or increased to 2mm if rigidity-requirement is of importance. In the "metabin" shown in the photo, walls of 1.6mm give the greatest volume, fastest print time, and ability to extrude exactly 4 paths at 0.4mm nozzle width, in FDM printers.

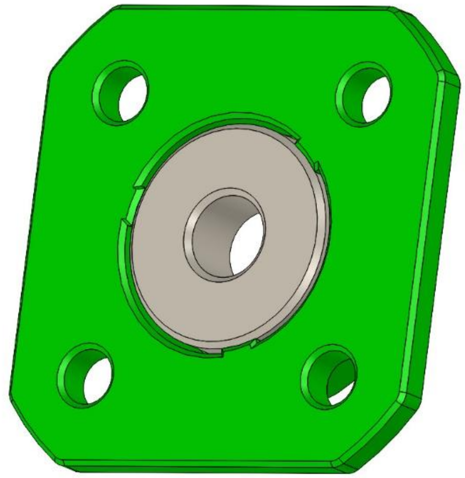
Retention with concentricity

Retaining a round feature like a bearing is made with three contact points. Clearance size is chosen for the noncontact region and interference size is chosen for the contact regions. The contact regions are made rotationally symmetric with a parent feature designated “vertical” and aligned with a main plane such as “front plane.”

The Hub shown below performs retention of the bearing and achieves concentricity when the mate is realized.

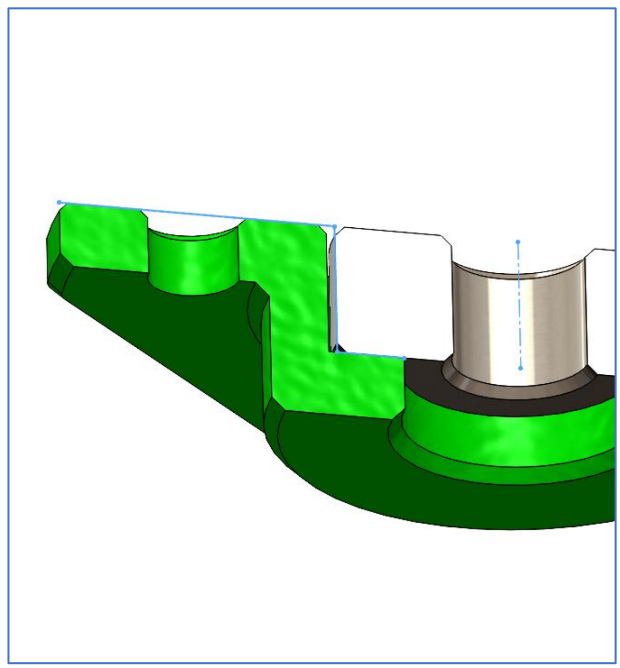


The disc retention is evident in the next photo: see three revolved bosses which contact the bearing.



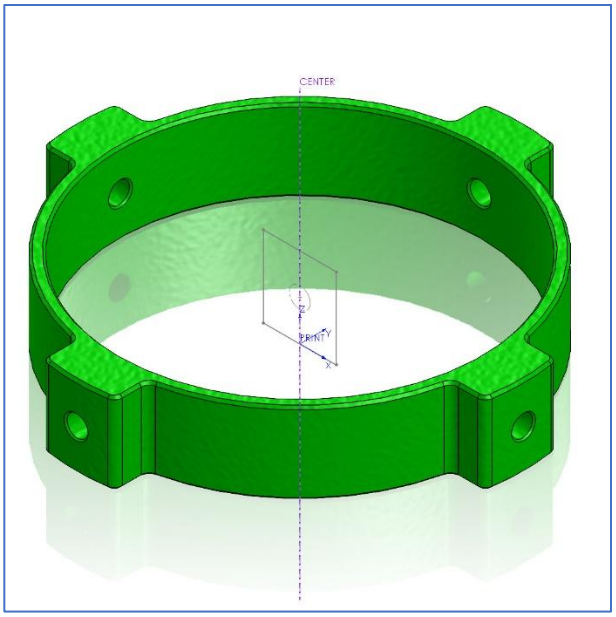
In this design, the bearing diameter drives the design size so this diameter is drawn into the model at the earliest stage of modeling. Sketches are higher priority than feature parameters so the sketch defines this geometry.

See the blue line in the next image which is revolved and thickened to build the solid.



Holes in round tube - Fabricating

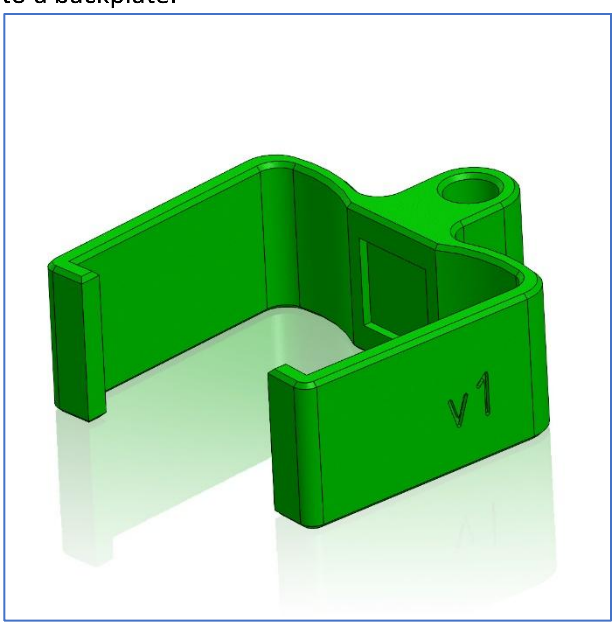
If holes are to be designed in round tube then they are designed symmetric at 180 degrees. This alleviates effort in any drilling & tapping operations such that the technician can drill holes which pass through the part. Measuring locations at 180 degrees is far easier than other spacing selections. See the part called “holeGuide” which fits onto a PVC tube and creates a drill guide at 4 locations.



Compliance: Sigma Compliance

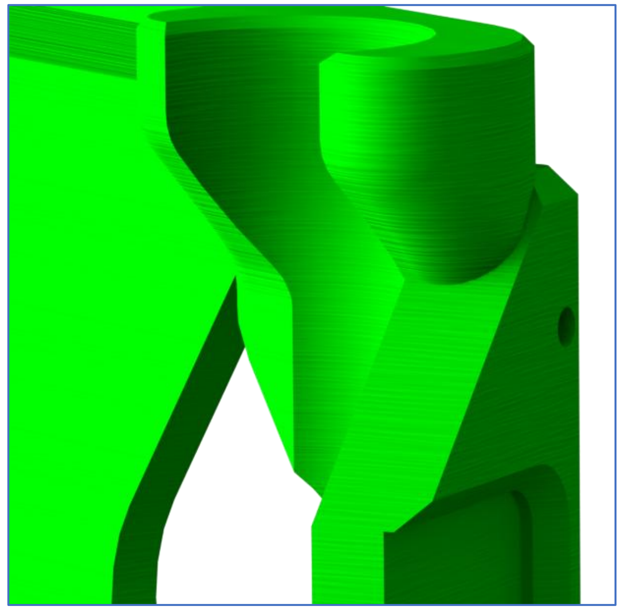
Sigma compliance is an arrangement for a compliant part to secure another part in 3 degrees of freedom. The part is mirror-symmetric, where the left/right sides include compliance in the weak direction, and a spring force is designed into the part in a “strong” direction.

The “gripping” like a human thumb + finger has a light force. The “clamping” like a spring action draws the part to a backplate.



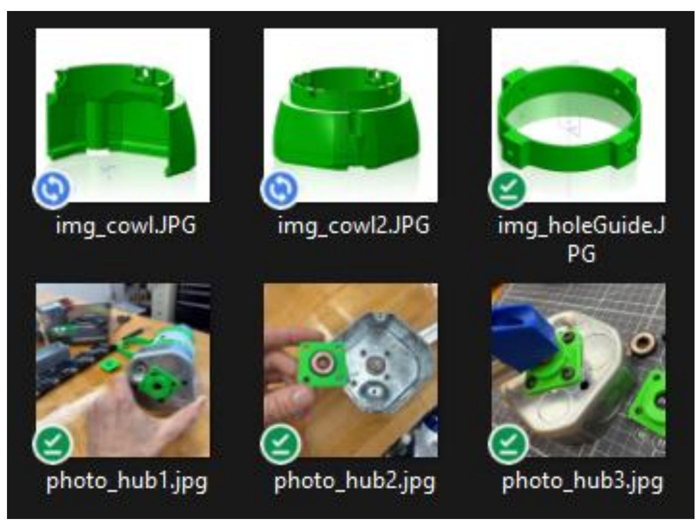
Part Appearance - Texture

The appearance selected for the part aims to reflect the texture of the 3D print. Textured appearance is optional but it becomes more important in certain situations. During modeling, this cues the designer into the grain direction of material. In publication, it communicates about the intention of the part. In the image below, the layer lines are produced in SolidWorks by adding a texture called “PW-MT11150” which is then stretched thin and wide (aspect ratio 6x60mm) and applied with the ”projection” to show layers aligned with the printing plane.



Part Images

Images are made in the square aspect ratio with a resolution of 2048 pixels wide. This offers the maximum flexibility in documentation. See the images in a directory in the screen snip for an example. Photography can produce other popular aspect ratios but most screen-snipping softwares can constrain images to square out-of-box and powerpoint slides are easiest to control with square images.

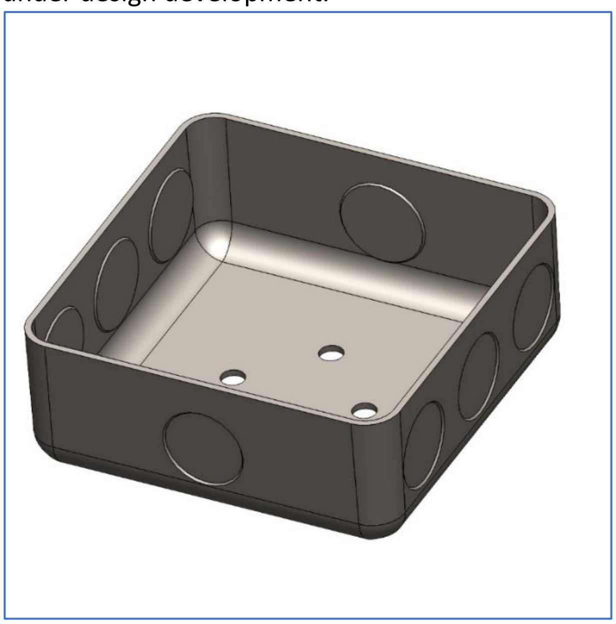


Parts Trees

High Degree of Variation

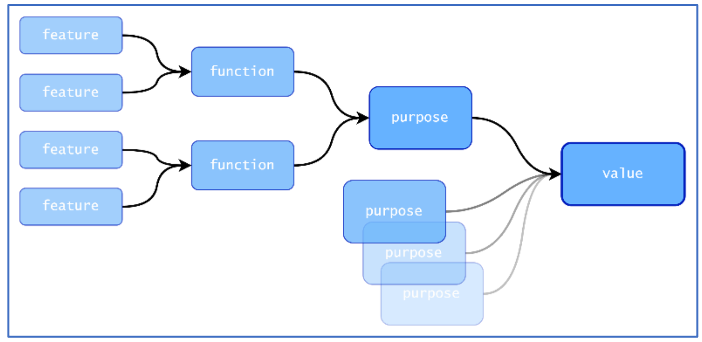
Some parts have parameters which contain more parameters and many variations that each have high-value applications. They quickly expand across multiple assemblies and projects and duplicate. For these parts the documentation required expands, and the community collaboration belongs at multiple levels.
The electrical outlet box called "handybox" by the Raco brand is one of these parts. The names and keywords become more complex, as redundancy appears across many documents. The image below shows a square-shaped handybox which is equally standard as the rectangular box.

When the part reaches this level of complexity the documentation requires more flexibility than a typical CAD model posting site. This part has been given a Github repository in addition to multiple grabCAD posts. The repository called "OpenBox_Project" receives a custom hyperlink at qr.net/openboxproject and several written explanations to describe the many functions that are under design development.



Feature, Function, Purpose, Value

These terms are used in many ways but a more specific definition will help with discussions of shared parts, redundant parts, parametric parts, and parts with many functions. The diagram below shows the relationships: features of a model are formed to establish a function. Functions are assigned as a design goal for a part. Multiple functions may appear in a part for it to serve its' purpose. When we talk about simplifying and reducing designs, we must reduce all the way until a further reduction will damage the function.
The value term specifically can apply at any level in the tree. Features which support more functions are high in value. A design (at the purpose level) which also has many sister purposes (supported by the same design elements) has more value.



A representative feature is possible, or a representative function, purpose, or value. In the next two images, we aim to establish the high value of the square handybox by demonstrating it can purpose as a robust bit holder, or it can purpose as an airflow distribution hub.

The next photo may intends to communicate a purpose in concept, before any CAD models are created. Actually the square handybox is already modeled and posted. At the moment of sharing the photo below. The two added components (pc fan and adjustable nozzles) have the functions of routing flow and directing flow, respectively. If someone is familiar with both of these parts, then they likely will ascertain the concept shown: we can use the square box as an airflow hub and easily design adapters to connect the components together to serve this function.


ideas still
flowing...
-DM 2024.07

Background

I'm nearing a point where each new CAD model takes very little effort, and I'm just producing the design from a set of rules. I'm making very few decisions. That means this is becoming systematic. A signal of proper engineering.

What is a software language? It's a system of syntax and rules to write instructions that a computer can interpret and execute. **
A software language provides a bridge between human thought and machine execution**

What makes a software language complete? (if I were developing C++, how do I know if it is finished?) There is an objective answer, and the most common reference is TURING COMPLETENESS: a language is complete when it can, in theory, perform any computation that a turing machine can, provided enough memory and time.

Is it possible to make a *mechanical set of elements* that covers all of the necessary components? If it's possible to make a complete textbook then it's possible to define a complete physical set of solutions. What makes this texbook (Mechanical Engineering Design) complete? It's a book for mechanical design. I think its when a collection of features can be formed into (nearly) any mechanical machine.

So if I can describe the system, describe what criteria will make it complete, then get help from other designers, then we can achieve the reinvention of everything.

The difference between these two parts is 3 floating point values. THREE! The hackers out there should be able to modify my CAD files in a matter of seconds - and then autonomously, thereby making each design into 1000 designs.

The CAD problem is now solved, in the way mathematicians write a proof. I built and released enough examples to demonstrate each feature and I want to ask for help.

Completeness
I am near a point of completion; of having a small set of functions implemented that enable any possible mechanism that can be desired.

Materials-Structure
1. plastic (abs & PVC)
2. aluminum (extruded 6061)
3. steel (fasteners, pins, balls)
4. steel tubes, EMT conduit, 1/2in and 3/4in trade size

Materials-Panels

1. Expanded PVC, 1/4in thick, panel
2. Foam sheets, around 25mm thick, porous, light compression
3. Rubber panel sheets, 1/4in thick, high-strength
4. Composite pegboard or smooth board, 1/4in thick

Materials-Laminate

* vinyl wrap, 12-in rolls
* epoxy, 2-part, odorless*
* cotton duck-cloth (like canvas, durable, flame-resistant)

Materials-Geometric

The maximum reduction of features leads to highly characterized parts
* steel round balls, bearings
* round tubes, copper
* round pins, wood & steel
*

Engineering-types

Product-Types
Parts function expressed by product names & trade names
1. one way valve
2. machine screw
3. structural tube
4.

Function-types
We need a rule to describe the meaning of "function" and it's relationship to a "part" since some parts can have multiple functions, and so on. This note is a placeholder to verbalize my rules for scale and spread and discretion between functions and parts.
1. handle
2. joint, load bearing
3. knob, turning
4. leveling foot, adjustable
5. wheel, free-spinning
6. four-bar linkage
7. structure attachment, tension
8. structure attachment, sliding
9. structure attachment, pin on plate
10. structure feature, plate mating

Rules

1. Material introduction: A material can only be introduced if accompanied by a method of permanent bonding to all other materials in the collection.
2. Fasteners: A fastener cannot be introduced except accompanied by the method to perform the fastening and the method does not expand the tools required in the tools collection.
3. Parts: parts must be assigned a tier where the tier 1 parts are the most simplified and natural form of the part and the number of parts in tier 1 is to be minimized. Tier 2 parts are those which can be described with the same definition as a tier1 part but having more specific details. (ie bearing at tier 1 may feature a family member "sealed bearing" at tier 2) The collection of parts will reach a finite limit and be expressed by the Tier1 parts overall.
4. Parts introduction: A part cannot be introduced which has a function already accommodated by an existing part in the collection. An introduced part also must include a standard method of integration and a most favorable example of integration which expresses the purpose of the part. The example of integration is to map to an example of a purpose of that integration which has been introduced at or before the part's introduction.
5. Materials Expansion: A new material is not to be introduced if the function can be achieved with the existing materials in the collection. A new material may only be introduced as an end-node in the assembly of a machine. The end nodes of a machine are that which can be interchanged without changing the design of the machine.
6. Parametric-OTS: Parts may only be added if they originate in a family which features variations of the key specifications. A tube is sold by length, then the length parameter must be variable continuously.
7. Metric-first: metric selections of parts must be used except if they operate on a supply stock based on discrete imperial units. The slotted Unistrut channel features discrete repeating geometry at two inch lengths and with 1/2inch holes, so the discrete inch values can be computed in metric easily without expanding the mathematics tabulated in our design files.
8. Permanent Joints: Permanent joints always accompany a method for joining which is defined with the minimal supplies and geometric features necessary. with a method such that future jointsmust integrate the same joining method that is best-qualified to-date unless the joining method is not suitable.
9. Permanent Joining: the permanent joining

Rules-Bonding
1. Joining is divided into PERMANENT and TEMPORARY bonds.
2. Example Piece: web.sldprt
    1. The bonding uses a compatible adhesive, chosen before design of geometry
    2. The mating parts are constrained in all DOF except for one, before using adhesive.
3. Adhesive only constrains 1 degree of freedom.
4. Adhesive is planned to carry load in shear-direction (not pulling)
5. Ideally, no priming. Use primer if performance isn't achieved with pure adhesive

Rules-Modeling-Features

1. A model should use the fewest dimensions to form the concept.
2. If the concept grows to have an added function, (see example: bearing & pvc) there must be made an additional model.
3. The model matures when it can gain new functions by adjusting only one dimension. The adjustment of this dimension becomes the utility of the part. In the parametric bearing, I can purchase a new ball, input the new diameter, and the model gives a new design for the bearing size, which can export to STL and make a part. All further variations become a new model with new descriptions, and should note their "root model" from which it started.
4. Implement symmetry to reduce the complexity of a model. In many models the main body is extruded up from the top plane. The model is improved by returning to the first sketch & extruding from sketch as "midplane." This has a cascading effect on models, adding far more power to constraints like "symmetric" and "equal length."

To finish this project

1. must finish the collection of templates. To logically check if the collection is complete we can use the machine-planning concept. Imagine a desired machine to be built with the collection. The machine should be able to be reproduced with the collection at-hand. If it cannot, we explore if a simpler execution of the machine exists which still achieves the defining function. If we find a simpler machine, we displace our present selection. We continue reducing the machine concept (performing machine reduction) until we find the simplest execution. Then we review if the final selected machine can be built with our collection and if it cannot, we ask what portion is not possible.
2. If it cannot be built with the collection then

Reduction-Efforts
* Use a template material for *

Goals-Hoshin

Particular goals are continually applied, continually improved, and never quite complete. These goals are strong enough to become rules but they lack a discrete (yes/no) validation method.

**

The apparatus shown above is an example design which has the **minimal necessary parts** to demonstrate the function of the selected water pump. We need to be able to answer all the questions in our examples:

- What is the flow rate (with flow that is visible to the eyes)
- How much power is consumed by this scale of a pump?
- How much control do we have to adjust the flow without changing the actuator selection?

same

as having as having impulsive decisions, but such description is oversimplified. Instructors face constraints on their