Intro:

Many museum and public displays of dinosaurs are either real skeletal recreations based on recovered fossils found in stone, with casts being made from them or public attraction pieces that are made of hard plastic required by their kid friendly and outdoor placement (*Tyrannosaurus rex,* OnlyDinosaurs) [INSERT DINO IMAGE]. This model prototype provides a different perspective of a T-Rex skull intending to combine both the skeletal structure and a skin imitation of a real T-Rex. With this model intending to be a hands off, display model various child-friendly concerns wont have to be the top priority during the design and development phases.

Model aims:

This model needed to be visually appealing, with a good blend of a realistic representation of a T-Rex skull’s bone structure combined with an outer skin design that represents the creature’s flesh. In addition, the lower jaw should move allowing for it to be opened and closed on a bearing joint inside the skull, this joint needed to be a fluid motion that’s strong enough to hold the jaws weight. This model should also be safe and durable enough to be in an enclosed display environment for extended periods of time, while also being able to survive accidental contact. Notably this model is designed for indoor artificially lit rooms.

Constraints:

The model needed to be lightweight and easy to handle in order for easy relocation inside a display environment, as well as aiding in reduced jaw bearing complexity as a light jaw subjects the bearing to less force.

The material costs had to be considered as this model was developed under a budget.

Design fabrication time and environmental effects were also considerations that had to be taken into account, as this model aims to be as least environmentally damaging as possible. Material choice prioritized biodegradability and minimal harmful fumes during production, leading to the selection of PLA filament (Boissonneault, 2023, (Bluhm, 2022).

Design:

The design phase focused on translating the goals of the project into a tangible, working solution. The availability of 3D modelling software such as Autodesk’s Fusion 360 was a critical tool that was used during this phase of development. It facilitated the rapid modelling of various aspects of the model, including a 3D printable bearing for the jaw mechanism, and spring mounts to ensure smooth jaw movement.

Bearing:

Justification:

For the jaw movement a bearing, situated at the connection point between the lower and upper jaw segments, was to be used. The decision to design and 3D print a bearing was made fairly quickly, this was down to the cost of procuring two ball bearings from a retailer being too high, with one unit costing in excess of £21 (RS, 2024). Designing and printing a print-in-place substitute was much cheaper and was ultimately the path that was taken.

Design considerations:

Whilst a usual bearing surrounds balls in walls to contain them, this was deemed as unnecessary and potentially worse as 3D printing perfectly spherical balls can be a challenge, owing to the extreme overhangs at the tops and bottoms of them as they are being printed. To reduce wasted prints, rollers which increased in diameter at the ends were used instead. This allowed the “ball” substitutes, rollers, to roll while not falling out, similar to a train wheel design. [IMAGE OF TRAIN WHEEL AND CROSS SECTION OF BEARING PIN]. Whilst the negative was used to form the centre and outer casing.

Design challenges:

The initial concept for the bearing incorporated 45-degree chamfered edges. However, limitations with 3D printers not being able to print excessive overhangs (Kondo, 2023) necessitated a redesign for improved printability. The bearing was redesigned with a 60-degree cut-out leaving a 30-degree chamfered edge allowing the overhangs to be printed correctly, in place without any supports which would result in wasted materials and energy.

Material choice and trade-offs:

Polylactic Acid (PLA), a common and easy to work with filament was chosen as the material for the model to be made of. With the model intending to be used as a display piece, extreme durability and strength wasn’t required. PLA is a strong enough material to support its own weight while being transported or touched, if the model was prone to being dropped an alternative material such as ABS would be a better choice (TWI, 2020).

Fused Deposition Modelling (FDM), results in visible layer lines affecting the surface smoothness of the model. For an initial prototype that doesn’t require perfect operability, a layer height of 0.2mm was used. This leads to obvious lines in the print that will affect the roughness of the inner bearing and the rollers. However, 0.2mm was chosen to save on material cost and printing time, a final bearing could be printed with layer heights all the way down to 0.08mm to increase smoothness.

Moreover, PLA is a bioplastic being commonly made of fermented plant starch (BioPak, 2024) which can be recycled to create new filament or composted into carbon dioxide and water in less than 90 days in a controlled environment (*How sustainable is PLA 3D printer filament?,* Kinworthy, 2024). All while emitting fewer harmful fumes during the printing process than alternative materials like ABS (Xometry, 2023). This led to its selection for use in all prototype models.

Initial design

The design of the bearing was created using Autodesk’s Fusion 360, its parameter focused design capabilities allowed for precise control of every section of the model. The precise extrude mode allowed for accurate control of dimensions. In addition, fusion 360’s circular pattern feature allowed for easy duplication of the rollers in a symmetrical pattern.

As stated above, the initial design of the bearing involved 45-degree chamfered edges, however this was determined to be unsuitable for 3d printing. Therefore, the bearing was redesigned to only allow a maximum of a 30-degree overhang, which results in better printing performance. The inner roller was designed first:

[INNER BEARING STL]

Only one half was designed as the bearing will be symmetrical about the z-axis. The inner-smaller section was designed to be half the size of the chamfered section. This design was incorporated into the main body that included an inner circle and outer-ring that were extruded up to 20mm and then given a chamfered edge of 30 degrees.

[MAIN DESIGN VIDEO]

This process resulted in the final design of:

[BEARING STL]

This bearing prioritises both maintainability and functionality, it is intended to be press fit into a cutout inside the skull of the model. This will allow for the ability to swap out the bearing if it breaks without needing to replace the entire model, while still ensuring the structural rigidity needed for a static display piece. The jaw component of the model will feature a hexagonal shaft designed to interface with the bearing’s internal bore. This provides excellent grip ensuring the jaw doesn’t slip when trying to be moved. The shaft is as follows:

[SHAFT STL]

A 3D scan of a T-Rex was the initial plan for the main body of the model. 3D scanning allows the capture of physical objects into highly detailed digital, three-dimensional models (Rankin, 2023). This process involves projecting lasers or structured light patterns onto an object’s surface while cameras capture how the light distorts. Specialized software then analyses these distortions to extrapolate thousands of points in space, forming a point cloud that meticulously describes the object's form (Explaining the 3D scanning process: How it works 2023). 3D scanning is ideal for complex surfaces or objects that require massive amounts of data for accurate representation. It eliminates the guesswork of traditional modelling methods and can be far more practical than using a touch probe (What is 3D scanning? 2016). 3D scanning has widespread applications, from reverse engineering and product design to medical modelling, historical preservation, and even quality control in manufacturing (*Best uses of 3D scanning and its applications*).

A handheld 3D scanner was to be used in-order to generate an accurate digital version of a T-Rex’s skull, however a model representation of a T-Rex’s skull couldn’t be sourced in time for this projects completion, therefore an existing digital representation was to be sourced and used. Two 3D scans of real T-Rex skulls were identified and collected as reference material (*Tyrannosaurus Rex (NHMW-Geo 1998Z0049/0001) - 3D model by Natural History Museum vienna (@NHMWien); T- Rex Skull - Download Free 3D model by Laser Design (@laserdesign)*). These were used as reference in order to modify a preexisting 3D printable T-Rex model (Thingiverse, 2014). It was determined that the skull and jaw should be more pronounced and defined than in the original, in addition a complete redesign of the teeth were desired.

To add additional detail onto the skull and jaw of the T-Rex, a haptic modelling pen was used to add additional contours and recessed areas to the model. A haptic modelling pen is a motorised device that applies force feedback to a user, in accordance to a digital model. This allows a user to ‘feel’ the model as they manipulate it. Haptic touch pens are intended for use in simulation, skills assessment, virtual assembly, robotic control, collision detection, machine interface design and mapping (3D systems, 2023). For this project, the haptic pen was used to sculpt the original model into an improved, higher-detail design based on the reference material. The ability to feel the model and 'pop into it' using the pen allowed for a quick turnaround when modifying the model. The force feedback provided a more intuitive sculpting experience compared to traditional digital tools such as Blender, allowing for rapid iteration and ultimately resulting in a superior model.

[IMAGE OF PEN]

[ORIGINAL MODEL]

[NEW MODEL]

Blender, a powerful 3D modelling application, was used to design the individual teeth and was used to generate a full set that can be replaced on the T-Rex model. A basic cone shape was extruded and deformed to achieve the required shape. Subtle variations were created to ensure a unique looking set. Blender’s array modifier was employed to create multiple instances of the tooth. These were positioned, scaled, and rotated into the desired place in-order to create a full set (Blender, *About*; Blender, *Modeling*).

Blender’s versatility and accessible nature make it an extremely popular tool across various industry sectors. Studios often use blender for modelling, animation and effects in films and television. In addition, Blender is extensively used to create 3D game assets and environments. Blender has the ability to directly export model creations into stl files, allowing for the quick printing of any model created (Chillingworth, 2024).

However, Blender has a steep learning curve due to its vast feature set. Complex renders and simulations can be extremely hardware intensive, requiring power machine to operate efficiently. Moreover, it doesn’t contain the precision tools needed for highly accurate technical modelling that would be required to create a bearing for example (Southernshotty & Hassenfranz, 2023). It was for these reasons that Blender was only used to create the teeth, which were more artistic than technical.

Resins have become ubiquitous across various industry sectors due to their impressive versatility. In the automotive sectors, resins are crucial for creating lightweight, high-strength components like body panels. They offer excellent durability and design flexibility compared to traditional methods (Insights, 2023; Polymers, *Automotive*). Meanwhile, specialized materials like silicone rubber can be used to create realistic-looking skin for applications like prosthetics, special effects, or even animal models such as this projects T-Rex. Its flexibility allows it to conform to irregular surfaces and provides a paintable surface for a customized aesthetic. However, silicone-based skin solutions can be expensive and challenging to work with, resulting in potential defects. Additionally, silicone rubber often has lower tear resistance, requiring careful handling to ensure longevity.

Challenges

A significant challenge arose when attempting to convert the highly detailed T-Rex model, particularly the skull and jaw sections, into a parametric model within Fusion 360. Fusion 360 relies on parametric modelling to ensure precise dimensions and allow for easy modifications (McGarry, 2023). However, highly detailed models, especially those derived from sculpting, often consist of irregular mesh structures. Translating these complex meshes into a format that Fusion 360 can manipulate requires substantial computational power. In this case, the sheer number of polygons in the T-Rex model overwhelmed Fusion 360's conversion tools. This process proved excessively time-consuming and ultimately impractical for the project's scope. As a result, features like the bearing shaft, the negative space it requires, and the set of teeth couldn't be directly modelled onto the jaw and skull.

Conclusion

The design process of this T-Rex model successfully demonstrated the power of combining various digital tools and fabrication methods. This project demonstrated the adaptability of design workflows in response to challenges, such as the unavailability of a physical T-Rex skull for scanning. By sourcing an existing 3D model and utilising a haptic pen for detailed modifications, a realistic and unique representation of the T-Rex skull was achieved.

A comparison of 3D printing materials was conducted, and as a result PLA was chosen as the material of choice that the models will be made of. PLA’s biodegradability made it a responsible choice for rapid prototyping. Fusion 360 and Blender was used to create various models that would come together to create a final model.

Development:

The development phase focused on bringing the digital designs into a physical form using 3D printers. The 3D models created in fusion 360 and Blender were exported as STL files as this file type ensures the model is a whole shape, without any cuts or holes in it (*LEARN HOW TO PREPARE STL files: Stratasys Direct* 2022). A slicing program, such as Cura, is used to convert the STL files into G-code, a layer-by-layer set of instructions, that a 3D printer can understand. Slicing settings like layer height, infill and support structures were considered to carefully balance print quality, material usage and wastage and printing time. As a result, as this model is only a prototype, a layer height of 0.2mm was used, while an infill setting of only 8% was selected. This results in a ‘strong enough’ model that isn’t too aesthetically pleasing but is very quick to print and doesn’t use a lot of material.

The printing process involved heating the print bed and filament extruder, followed by the printer following the path of the G-code while depositing molten PLA. After printing is completed, the support material is removed, and the model can be inspected.

[FIRST MODEL]

After the first iteration of the bearing was printed, it was discovered that thermal expansion was experienced, that resulted in the rollers being attached to the outer ring of the bearing, resulting in a bearing that couldn’t function. This was tackled by adjusting the thermal expansion composition setting inside of cura. This resulted in a moveable bearing prototype.

[SECOND MODEL]

While the initial design envisioned a realistic representation of a layer of imitation skin made from resin which would be applied to half the T-Rex. Due to time constraints, this addition couldn’t be implemented during this project. This realistic skin texture would have further enhanced the model’s visual appeal.

Conclusion

The design and development phases of this project successfully showcased the power of combining digital design tools like Fusion 360 and Blender with 3D printing technology to create a functional model. The project demonstrated the ability to adapt designs based on challenges, such as the inability to 3D scan a physical T-Rex model. The use of a haptic pen allowed for rapid adaption of a pre-existing 3D model to create a unique version of the model. The prototype models were printed in PLA due to its combination of strength, easy printing, cheap nature and biodegradability.

Future works

If this project were to continue various additions would be made:

A design for a base plate would be constructed and made out of laser cut acrylic, with an embossed name plate. Laser cutters can be used to create lightweight components with intricate details, it can also be used to engrave words or additional details onto models. However, acrylic isn’t the strongest material as it can be snapped easier than other materials, moreover, laser cutting can produce some very harmful fumes (Velling, 2024).

Motion capture could be used to animate the T-Rex model, replicating realistic movements. This would create a dynamic and interactive experience, allowing viewers to observe lifelike T-Rex behaviour. However, challenges in integrating servo motors and processing large amounts of motion data would need to be addressed.

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