Abstract

Plant and equipment design in a two-dimensional environment provides a limited facility for the designer to fully review the interactions of all components involved in the final assembly. This leads to clashes and component mismatches which can result in costly rework and, possibly even worse, time delays for project completion. A full three-dimensional model enables a team of designers to work in collaboration such that each part of the plant or equipment can be virtually built and assembled to ensure fit-up and identify any possible clashes before fabrication commences. In addition, the three-dimensional modelling facilitates the transfer of required components of the design to finite element analysis packages for evaluation and design optimisation based on required component strength. The development of an intelligent model also allows parametric formulas to be assigned to the components, which enables quick model changes for different equipment size requirements without the need to redraw each component.

This paper describes experience gained during the design and fabrication of equipment for the recent Ubombo Chainless Diffuser project, and highlights the benefits of a three-dimensional design environment from concept through to installation.

Keywords: design, 3-D modelling, equipment, software, diffuser, fabrication, FEA, parametric design

Introduction

Three-dimensional (3-D) design is not a new concept, although few engineering companies in South Africa use it to its full potential. There are a myriad of software choices available, each with features that must be carefully considered to align with the needs of the designer using the program. Features such as finite element analysis (FEA), ‘automated’ structural detailing, bill of materials generation, optimising material usage, clash detection, sheet metal design, exploded views of complicated assemblies or subassemblies, and animations, can all be incorporated into the design process. Essentially, the process creates a ‘virtual plant’ – a digital prototype – that can be examined, simulated, reviewed and re-examined. Successes during the design phases translate into savings during fabrication, with design intent being communicated with greater ease to the fabricator. Ultimately, this results in a higher quality product for the client.
General

When 3-D design of the Bosch Chainless Diffuser commenced, Bosch agreed to adopt the parametric design approach. Parametric models are created with the ability to allow for easier change according to the design criteria. The model is built with the ability to hold intelligence; a set of rules to know how to respond to inputted changes. This provides many benefits.

Primarily, the designer can use a ‘shortlist’ of inputs that will ‘drive’ the overall model changes. Many equipment designs are volume driven. With parametric modelling, formulas can be incorporated to calculate diameters, lengths and heating surface areas, and output the desired model within minutes. This would typically take hours, if not days, with conventional two-dimensional (2-D) methods. The models then reference 2-D drawings, which update to about 90% completion, leaving the draughtsman to do some drawing housekeeping before the final revision is issued.

In addition, the intelligence resides within the model, and not with the designer alone. This allows almost anyone with a basic knowledge of the design to enter new values, and produce a new design. Of course, the responsibility of knowing whether the new design will function as expected still resides with the engineer.

However, it is also not always possible to conceive every aspect that could change within a model, with design permutations potentially running into the thousands. The main dimensions, driven by the engineer’s design, are therefore set as the primary inputs and a set of sub-rules applied to dependant components. As an example, the diffuser width required is determined by the process throughput. The number of internal moving screens required is then a direct relationship to the width, and the parametric model can be programmed to do this calculation without additional user input.

In engineering design, there is always the client-specific requirement and customisation. Obviously, the parametric design cannot automatically cater for these special requirements, but it can drive the design into the standard form quickly, which allows the designer to add the specific and additional requirements to the 3-D model. This approach is faster than starting from a zero base each time.

A factor that could be construed as a negative aspect of 3-D parametric modelling, is the upfront man-hours required. On a one-for-one comparison against conventional 2-D designing, the parametric models typically take longer to construct, as accurate linking of values and formulas are the only way to ensure success of the models later in their life cycles. This process should, however, be seen as an investment, as the future applications of the model, say for preparing a client proposal or actual fabrication drawings, would benefit the project by reducing the designing hours required. The quick turnaround time could also mean the difference between meeting or missing deadlines, as well as being an impressive marketing tool. Imagine a client request arriving in the morning and by the afternoon a proposal drawing is on their table. This obviously depends on the complexity of the model, but Bosch Projects has actually produced a full set of signed-off design drawings for a vacuum pan from the Process Engineers design program within two hours.

Somewhere boundaries have to be imposed, as the designs materialise as tactile drawings with limited paper space and defined margins. As a general rule, it is safe to assume that
equipment will almost certainly not get larger than the preconceived absolute maximum. However, there are inevitably exceptions to the rule. A case in point, when parameterising a 3-D Long Tube evaporator (LTE) to a maximum size of 6000 m², the very first set of drawings requested after the model was completed was for a LTE with a heating area of 6500 m². It would still be quicker to make the changes to the paper boundary limits from the model than having to recreate the design in a conventional 2-D design package.

The benefits of 3-D design, even without the parametric element, are numerous. To be able to visualise a design and watch it take shape allows the designers and engineers to identify errors early in the design process. When drawing in 2-D, designers must mentally combine multiple views in order to visualise what the design will look like in 3-D. This can only be comprehended with practise and continual exposure to the design environment. What is difficult for engineers and drafters to understand may then be impossible for non-technical customers, buyers and suppliers to fully understand. Looking at a design in 3-D versus 2-D allows the design to be communicated much more effectively.

The ability to generate 3-D images also makes it easier to communicate with others besides customers. Operations staff, contractors and management may also find it challenging to interpret a 2-D drawing. Yet they will readily understand the design when presented in 3-D, where one can rotate, zoom, and even ‘walk through’ the proposed designs. The diffuser construction team was greatly assisted by having the 3-D model to add explanation to the complicated assemblies. Refer to the 2-D drawings of the diffuser retract frame (Figure 1) and the 3-D view (Figure 1 insert) that provides a much easier presentation of the arrangement.
Figure 1. Diffuser retract frame plan view and elevations.

Insert: Isometric view from the 3-D model.
In addition to presenting the engineered item as a 3-D view, the ability to show customers a ‘video’ of the equipment in action not only communicates how the machine will function, but also provides an edge over others who are submitting 2-D drawings in the quoting phase. With the understanding gained from the 3-D images and 3-D animations, potential customers feel more confident about the design proposal and what will be delivered as a finished product. The equipment can be animated through its full range of motion while continuously checking for collisions between parts. For the diffuser project, the animation of the kicker over the drawbars was used to confirm clearances of the tynes and indicate the cleaning action that was desired. Figure 2 shows a still frame from the kicker animation.

Figure 2. Snapshot of kicker animation.

Other examples of using this 3-D animation include the motion of the lifting screws in the event of a shear pin failure, the moving screen motion and hydraulic cylinder stroke required, and the juice heater lids, where the lid had to make contact with the shell with no scraping of the gasket face.

For designers, creating 3-D designs is not only rewarding, but provides the mechanism to convey the design intent much better than a traditional 2-D computer-aided design (CAD) drawing. To get inside virtual equipment provides a unique perspective, especially so early in the process. Typically, the first time anyone sees the equipment, it is already on site, and it is therefore far too late to implement design changes. Not so with a 3-D model. As 3-D designers construct the virtual model, so the engineers can ‘peer over their shoulders’ and spot any changes that need to happen.
Similarly, in this manner, 3-D models also allow engineers to easily identify and anticipate problems, thus saving time and money by eliminating the problems before getting to fabrication. In fact the diffuser project only had a single case of rework required, and this was due to a manual intervention of red-lining a drawing at the contractor’s works.

The standard set of 2-D drawings for the diffuser lifting screw had an inherent flaw with a clash of the shaft shoulder with the bearing housing. Although checked on numerous occasions, the error was not identified until the components were modelled in 3-D and virtually assembled. The clash was then clearly evident (interference highlighted red in left image of Figure 3) and rectified (as shown in right image of Figure 3).

![Figure 3. Shaft and housing clash detected (left), and rectified (right).](image)

The speed at which designs can develop in 3-D, considering that drawing changes are on average quicker than traditional 2-D CAD drawings, allows engineers to get to the final design faster. Because of the quick changes, more iterations of the ‘what if?’ kind between the initial concept and the final chosen design can be executed to achieve the best design outcome. During these design phases, designs can be FEA tested, sent out to consultants and suppliers, and returned to the system for further revisions, all within a short time period. This allows ideas that are difficult to construct to be simplified, once again resulting in a higher quality product for the client.

The way in which the 3-D modelling is quicker is in its ability to provide automatic view creation for any 2-D view needed. In other words, from the 3-D model, various 2-D views can be created, including section views and detailed views.

Also, in 2-D, whenever a change occurs, every drawing view has to be manually updated. This can be many views which need to be updated manually each time a design change is
made. For example, a minor change to a dimension on a part triggers a series of updates. On large assemblies, this minor change could mean hours of work, with a high potential for errors or omissions. In the diffuser, there are over 3500 unique parts, with over 30,000 total part instances. (A specific steel frame or step, for example, only has to be drawn once as a unique part and then can be used in multiple assemblies as part instances.) Much of the available design time could be spent just trying to keep all the drawing views up to date as the design develops. For changes made to the diffuser 3-D model, such as a change in bolt and hole size, a single instance is changed which then automatically ripples through to each assembly and every drawing view.

New projects can reach advanced stages very quickly using the parametric model approach, as it allows easy reuse of existing designs to create new versions or configurations.

In addition, 3-D models from suppliers of equipment such as motors, gearboxes and pumps, can also be incorporated into the design model. This not only enhances the visual fidelity of the model, but also ensures that the selected models or components fit within the design.

The impact of the time saving can be quantified. Tables 1 and 2 give the design times required for relatively complicated equipment assembly.

### Table 1. Indicative time saving for equipment assembly (pan).

<table>
<thead>
<tr>
<th></th>
<th>Conventional 2-D design (hours)</th>
<th>3-D parametric modelling (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup/Investment</td>
<td>0</td>
<td>560</td>
</tr>
<tr>
<td>Time to design</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>Total design time required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Unit</td>
<td>100</td>
<td>570</td>
</tr>
<tr>
<td>2 Units</td>
<td>200</td>
<td>580</td>
</tr>
<tr>
<td>3 Units</td>
<td>300</td>
<td>590</td>
</tr>
<tr>
<td>4 Units</td>
<td>400</td>
<td>600</td>
</tr>
<tr>
<td>5 Units</td>
<td>500</td>
<td>610</td>
</tr>
<tr>
<td>6 Units</td>
<td>600</td>
<td>620</td>
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### Table 2. More complex design time indications (diffuser).

<table>
<thead>
<tr>
<th></th>
<th>Conventional 2-D design (hours)</th>
<th>3-D parametric modelling (hours)</th>
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</thead>
<tbody>
<tr>
<td>Setup/Investment</td>
<td>0</td>
<td>4 000</td>
</tr>
<tr>
<td>Time for outline</td>
<td>1 600</td>
<td>600</td>
</tr>
<tr>
<td>Time for detailing</td>
<td>2 400</td>
<td>1 600</td>
</tr>
<tr>
<td>Total design time required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Unit</td>
<td>4 000</td>
<td>6 200</td>
</tr>
<tr>
<td>2 Units</td>
<td>8 000</td>
<td>8 400</td>
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<tr>
<td>3 Units</td>
<td>12 000</td>
<td>10 600</td>
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<tr>
<td>4 Units</td>
<td>16 000</td>
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<tr>
<td>5 Units</td>
<td>20 000</td>
<td>15 000</td>
</tr>
<tr>
<td>6 Units</td>
<td>24 000</td>
<td>17 200</td>
</tr>
</tbody>
</table>

As shown in Tables 1 and 2, as the assembly becomes more complex, the investment time increases proportionately but the payback period reduces. (The hours stated above are based on Bosch Projects experience on recent projects and extrapolated for additional units.) Three
units are expected to start returning added business profits as the conventional 2-D design would have a correspondingly high man-hour requirement for each design. The 3-D system also has the added benefits discussed in this paper.

The Bosch Projects 3-D modelling design approach was not easily implemented. As with any major change to systems or methods of doing standard tasks, there is the human element that is resistant to change. This was experienced at both management and user levels. “The old way has served us well for so many years, why must we change?” This is the most common obstacle that has to be proven wrong before complete buy-in is reached, and is often done on trial software on small projects where the financial ‘risk’ is low. The other difficulty is in the selection of the correct software to use to perform these tests, and often multiple tests and trials have to be run on various platforms to find the best fit. This takes time and a dedicated team to carry out the tests and perform the evaluations. Time, being a commodity in the consulting business, is deemed precious and hence it is sometimes difficult to get approval for trials. Another hurdle is the new set of skills required to develop in a 3-D environment. It takes a different mindset and of course the new software has specific commands and functions that need to be mastered. Bosch Projects had limited designers capable of using the new software, which created a huge workload for those individuals working on the first few projects. There was also the unknown of how long drawings would take, so planning was very difficult and deadlines were overrun because of the learning curve experienced by the designers.

In addition to the time aspect for the implementation and the training, is the actual software cost that is incurred for setup and the ongoing licence and service fees.

When a project requires the collaborative effort of several parties such as suppliers, contractors and engineering, procurement and construction management (EPCM) teams, the use of 3-D design creates an environment where the separate contributions can be combined as a single model. Once in the common model environment, connection interfaces and termination points can be examined for consistency. A practical example of this was the piping and conveyors from the EPCM team being combined with the diffuser model and viewed in the same environment. This made it much easier to spot potential dimensional errors, missing connections and clashes.

In addition, all the external piping can be modelled and incorporated in the common model to check connection points and any collisions or clashes. The diffuser design utilised separate design programmes for the equipment and the piping, with only the important connection points being exported from the diffuser model as design reference points. This method identified numerous clashes before the drawings were issued. It also highlighted the exact tie-in points between contracts that may have otherwise been miscommunicated.

Designers can assign a material type to a part which allocates densities. Depending on the program used, this information can be grouped to indicate the assembly mass and centre of gravity. This also provides the ability to generate an accurate and current bill of materials (BOM). The BOM is always accurate because it automatically updates with any changes made to parts and assemblies. This facilitates cost estimates, both for current and future projects.

Design and/or fabrication errors can still occur despite the best efforts. When the designer cannot be on site with the contractor during erection, trying to explain those errors through the use of email is challenging. Even referencing 2-D drawings, it can prove to be difficult for a designer back at the office to visualise the problems. With the use of 3-D and lightweight
viewing models, site engineers can have a live view of the 3-D model, and navigate with freedom to the problem area. This can and has saved a great deal of time in being able to understand, analyse and solve problems as they arise on site.

Please refer to Figures 4 through 9 for comparisons of the 3-D model against photographs of the actual construction.

![Figure 4. 3-D model of diffuser lifting screws.](image)

![Figure 5. Photo of actual construction.](image)
Figure 6. 3-D model of diffuser stage piping.

Figure 7. Actual diffuser stage piping.
Figure 8. 3-D model of diffuser walkway and piping.

Figure 9. Actual diffuser walkway and piping.
Conclusion

3-D modelling and in particular the parametric approach is perfectly suited to tasks of a repetitive nature or for designs that are variants of a similar base structure. The diffuser, evaporators, continuous vacuum pans, reheaters and vertical crystallisers are examples of the latter. It is also beneficial for designing parts and complex systems that are difficult to visualise or that require many drawing views using 2-D layouts.

Reuse of 3-D data can save time and man-hours. This makes the design house more responsive to sales enquiries, as well as improving the quality of the designs, by reducing the incidence of design errors.

Sales and marketing can also reap the benefits of 3-D results as rendered 2-D images, 3-D assembly views with photo-like quality (see Figure 10 as an example) as well as animations can all be incorporated into equipment training manuals, uploaded to websites, and even posted on youtube (www.youtube.com/boschprojects).

3-D modelling provides a fresh view into the design process. It attracts and retains skilled designers and engineers wanting to use the latest cutting edge design tools, and can improve a company’s image to customers and vendors. In a major shift from the drawing board to the computer screen, 3-D design is yet another progressive step towards operating successfully in an ever-advancing digital world.

Figure 10. Rendered image of a Bosch continuous vacuum pan.