Industry 4.0 in Glass Processing

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A good hockey player plays where the puck is. A great hockey player plays where the puck is going to be. - Wayne Gretzky

Scope

Glass has a wide and varied use, from mass-produced glass containers for food of all kinds, to crafts with exclusive handmade single pieces. We limit ourselves to the flat glass industry, in particular to the processing of single pieces and small batches, with applications predominantly in construction (e.g. facades, windows, doors, showers, mirrors, kitchen splash backs) and interior design (e.g. display cases, furniture, and partitions).

This means I will not go into all mass-produced applications of flat glass such as windscreens, digital screens or solar panels. But there are many applications of flat glass in single pieces and small batches outside of construction and interior design, which also satisfy the criteria described herein and thus are included implicitly in the considerations below.

In connection with the processing of flat glass I will also look into its production, as far as is relevant for our considerations.

Terms and Definitions

With Industry 4.0 I mean the end-to-end digital manufacturing of complex products.

Under digital production as I understand it, comes the largely automatic production of products and components based on data which is stored on computers.

With end-to-end, I mean manufacturing that is digital along the entire supply chain, so that even the design and / or specification of the final product and its components are computer-assisted and automated as much as possible.
To start with, quoting should be automated as wide as possible. This should allow the flow of all relevant data along the supply chain as early as in the design phase. Specifications will be sent to potential suppliers and their systems should be largely able to immediately and automatically return a quote. If general discounts where negotiated with suppliers, they would be applied automatically.

Complex customer specific products are often developed and specified jointly in cooperation between end customer, the main contractor and his suppliers. In the context of industry 4.0 this will in the future take place transparently on a common development platform in the cloud. In the glass industry these are the complex major projects, whilst the daily business can be understood as mass customization.

**State of the Art**

**Mass Customisation**
Mass customisation is the automated production of customized products. As far as production technology is concerned, mass customization is possible and has been practiced in the glass industry for quite some time. Where in the glass industry products are tailored to customer specifications, for example insulation glass units (IGU) or showers in customized size and shape, there are already a lot of manufacturers producing with a high degree of automation. There are software solutions that facilitate the specification of such products massively and which can also largely automate quoting.

Many software solutions support the automated processing too, starting with the optimisation of the layout of the pieces on stock sheets for waste minimisation, followed by cutting code generation for glass cutters, as well as the data generation for machining on equipment for further processing such as drilling or waterjet-cutting for the production of cut-outs, through to controlling entire factories, beginning with the automatic loading of stock sheets onto cutting tables, over the caching of individual pieces in sorting arrays or harp racks and the control of insulating glass lines for the assembly of IGUs.
Interfaces in part already exist with suppliers within the glass industry, for example to purchase specific glass pieces from an external manufacturer, or for the specification of Georgian bars when they are supplied externally.

**Major Projects**

Many solutions in the glass industry also support the import of data from window manufacturing software, some of which in turn are able to import and transfer specifications directly from architectural CAD software. To my knowledge, however, there is still no platform on which large projects such as full glass facades for buildings could be developed in cooperation with architects, builders, metal builders and glass suppliers, although there would already be interfaces for the transfer of the data.

Modern facades are becoming increasingly complex. Regulations relating to thermal insulation, sun protection and glare protection mean that more and more components are involved (for example, sun gates, switchable glazing, solar protection systems in the window pane), but also for solar power generation or complete media facades using LEDs laminated into the glass. These calculations are becoming more and more complex. It would be a great help for the relevant experts if all suppliers would provide their products with their characteristics and costs in electronic form. This would simplify calculations, and once a decision is made, everything could directly be ordered electronically along the whole value chain.

Thus there is still great potential in that respect. However, it is not clear who is to build the platform, and who is more likely to be invited to the party. In my understanding it would be in the architects’ interest to manage the whole project, and thus invite the suppliers to participate in specifying the various components.

Where complex products are manufactured, there is of course a decomposition into parts and thus a return to the supply chain. If for example whole bathrooms are offered, the glass supplier becomes involved as supplier of showers and mirrors. Interfaces exist, however it is to be said that these interfaces have their roots in the DOS era and are not universal, meaning there will always be a certain percentage of specifications that do not go over these interfaces. Furthermore it is also to be noted that every supplier of window manufacturing software has their own export format and the interfaces between different glass companies often only work smoothly when the companies use the same software.

The bottom line is that many companies in the glass industry have already made good progress towards manufacturing 4.0. It is to say however, that there is much that could be improved. The long history of automation in this industry unfortunately also has the undesirable side effect that much software is still based on technologies that would no longer be chosen today.

**Current Problems**

Industry 4.0 is understood as the digital processing and networking of entire design, production and delivery processes. For comparison, the first PCs were only used locally and were at best only networked locally or via a floppy disk (that’s how cut code was brought to the machines back in those days), but were certainly not integrated into a global network as they are today with the Internet. In the meantime, much has been improved, crashes have become rare, but the PCs are still not perfect.
With Industry 4.0, we are now in the beginnings of networking these processes. This makes sense only if all parts are integrated, and if the production plants are sufficiently automated, so that the potential increases in efficiency are also realised.

Like the PCs in the analogy above, the production companies do not have to be perfectly organized in order to be able to make the next step of interconnection, but only well enough to make such an exercise worthwhile.

Ordering Process
To start I would like to look at the small business at the end of the supply chain. These are for example carpenters who amongst other things build windows with wooden frames, or glaziers specializing in the installation of purchased products and the replacement of broken windows. These businesses generally have no electronic interface to their suppliers. This often results in a sketch being sent, for example by fax to the supplying company. There, this order is entered and a properly scaled drawing is sent back with the order confirmation. If the customer can’t find his sketch in a hurry and does no verification, there is a risk that something wrong will be delivered.

A better integration of these customers, allowing them to order electronically would be desirable. As mentioned before there are applications from which the customer can order electronically, for example window manufacturing software. A PC based software application for small customers has not proven successful in the past. This only works if the customer benefits too, and provided he does not see it as an opportunity to get free maintenance of his system by claiming that installing this software created his problems.

Where safety risks are small, glass companies also supply to unqualified end customers. These are for example mirrors or toughened glass, always with polished edges, to make sure nobody can hurt themselves. In this area and for such a restricted range of products an automatic price determination would actually be fairly simple, but good solutions are missing or are at least not known to me.

Larger customers, for example window manufacturers as mentioned above, already order electronically. This works for the bulk of orders, but the interfaces should be unified and extended in such a way that even the most complex products can be specified within them and that they are further expandable. But smaller manufacturers, who can’t or do not want to compete with every technology, should still be able to work with a sufficient subset of such a specification.
Defects in Production

Damaged and broken pieces cannot be avoided completely in glass processing, even if working carefully can help a bit in this respect. However, this is not the problem I want to discuss here, but rather the way defects are handled during production.

In many larger plants, reporting of defects takes too long. Frequently glass is cut without the operator being up to date with regards to defects of pieces of the glass type as he is currently processing. In most cases, the re-production of these pieces could start much earlier, if layouts would be optimized at the cutting machine in such a way that these pieces get highest priority and are cut first. Instead they are often attached to the last sheet, along with the pieces that were broken during cutting of the current layout.

Statistical Evaluations

A common and frequent problem with statistical evaluations are the waste statistics. If you compare the data of stock sheets bought with the amount of glass sold, even with all the adjustments, usually you don’t even get near to the values the waste statistics provided from production software and factory floor feedback. This is in part due to the fact that the various programs of different software suppliers make largely varied evaluations, and it is difficult to bring this all together at the end.

For a start, waste is reported by the optimisation software. But this is usually only a small part of all the losses of material. Next you will try to factor in all the broken pieces. But that is where the difficulties start. If the piece breaks in cutting or shortly after, it might be best to quickly cut it off a rest sheet, to make sure the job does not fall behind.

Stock rests are an issue in itself. The optimization software usually does not report them as waste. Sometimes they are used in the next layout of that glass type, but that’s not always the case. Thus it’s not clear what to report as waste and what not.

Broken pieces are not the only cause for pieces to be produced again. This can also be due to defects in the glass or in the coat, or to scratches which have arisen during cutting or in the subsequent processing.

Furthermore there are the free replacements, where you just create a new job. In such situations it is frequently not really clear how this goes into the stats, if you simply compare glass purchased with glass sold. And then there is, of course, the loss that no one accounts for, as for example whole panels breaking, be it on the cutting table or during loading, or because they have to be removed because of edge cracks.

Loss that’s due to theft can never be ruled out completely either. But trying to proof such a thing by accounting for all other reasons until this remains as the only explanation, is most likely a long way to go and would still not deliver the culprit. If there is reason to be suspicious, it would be much easier to introduced appropriate anti-theft measures.

Statistical evaluations would help a lot in decision-making too, for example in regards to investments or for marketing purposes. Here we come to the topic of Big Data, certainly a tool of the future when used correctly. I will go into this a bit more in depth later in this paper.
Simulation
In the broader environment in the glass industry, simulation is already being used, for example in glass production. Quite a different type of simulation is used in the design of window fronts and facades. There it is often the case that only an all-year simulation can provide reliable information on the cooling and heating requirements and thus the fulfilment of regulations. Frequently in this area, only simulation leads to satisfactory results. This in contrast to the alternative rather superficial calculation methods, which always has to be on the safe side.

What I believe is missing are simulations of production plants with complexly linked machinery. These are often designed in such a way that most if not all the production can run over this plant. As a consequence the resulting (in-)efficiency for example in the production of large batches of identical products is sometimes neglected, as well as the cost-effectiveness in the design of the system and its ability to produce product variants which are rarely ordered and are only prominent in the heads of the employees because their production always creates problems.

In most cases simulation is to be understood in combination with optimization, whereby the optimization targets can often become quite complex, for example in a window front as the best compromise between comfort, lighting, outlook and costs, or a media facade between cost, functionality and payback time, or in a production plant as the best compromise between production and packing efficiency and waste minimization.

Defects
Defects in the glass are detected in the production process and known to the manufacturing companies, but the information is not passed on to the processors. Defects that are generally acceptable and only need to be excluded in exceptional cases are often discovered in later processing steps and then have to be eliminated by repeating production. The same applies to defects, e.g. scratches that occur during processing.

Processing-related defects can be reduced to a certain extent by improved statistical evaluations to identify the causes of defects. Defects in the delivered glass would have to be reported by the manufacturer, so that their incorporation into a product can be avoided. This is particularly important
with expensive glass, e.g. In the case of coated laminated glass with a defect in the coat. It is important that this defect information is known in advance to the optimiser so that the situation can not arise that the last large piece cannot be placed on the stock sheet delivered by the feeder because it has a defect in the centre.

Traceability
In theory the data required for good traceability are available in most automated plants. In practice, however, it is often the case that this data is not kept for a long time. In addition, the necessary evaluation software is usually missing. This can become quite complex, if you consider for example a piece that was broken in waterjet cutting and had to be produced a second time, but subsequently did not survive the heat soak test and thus had to be remade again. To keep track of which piece was ultimately delivered, from which stock sheet it was cut, and from which stock packet this comes, can become a challenge.
Opportunities

From Manufacturer to Service Provider

Manufacturers are increasingly changing from pure producers into service companies with a product component. The construction industry and the suppliers into it make no exception to this rule.

Recently, I had a discussion with a master builder in the mid-tier area. Here in Australia there are basically three ways to build a new house.

The cheapest option is offered by large builders. They sell house and land packages with a selection of standard houses. The customer still has options, which are usually associated with hefty surcharges. Standard houses are often designed to be oriented to the block of land (garage to the street), which does not always coincide with the best orientation to the sun.

The next option then is a plan which is derived from a standard plan, so that the orientation to both the land and the sun is right, and so that it caters well for the needs of the inhabitants. The most expensive option is the architect, who frequently cooperates with middle-tier builders in the construction phase.

In this middle tier is the builder I’ve been talking to. On his web site you can find all the standard houses that he usually starts from (about 100). Imagine now customers could enter their block of land there, its orientation to the sun, slope and gradient, access to the street.

The program would then automatically display the appropriate standard houses. Beyond that, customers can then further specify, e.g. number of rooms, but also construction standards etc., to narrow the selection further. It would also allow customers to modify plans. This process is running currently in cooperation with the builder. In the future this would run in the cloud, whereby at least a cost estimate would always run in the background and update the figures displayed. The builder could be involved at any time with advice and co-design. At best, a detailed specification and a binding quote would be available at the end.

All major suppliers could be integrated in this process as well. Each supplier could display his quote, and what is chosen is (ideally) bindingly quoted. Of course, the builder could limit the suppliers to those he trusts. Ideally some running costs would be estimated as well. For example with the choice of the windows there would be a calculation on how this would affect heating and cooling costs.

So this is another great example of a co-design platform of the future, where glass manufacturers could and should be involved. It does not stop with the specification and quoting process along the value chain. Building is not really a high precision operation, so while the measurements off the plan of say a kitchen splash back would be good enough for quoting, it would help to know exact measurements once the kitchen is in. Thus if there is a good relationship between them, then the installing joiner could just call up the plan on his tablet, point his laser to the wall and enter those exact measurements for the glazier before going home, saving the glazier the travel to the building site.

Cloud Computing and Logistics

The cloud is not only important in the specification phase, but also during production and delivery. Builders hate it when windows and other glass parts are lying around on the construction site for weeks, waiting for their installation.
If everything was ideally linked, the system of the window manufacturer would always know the state of their own order processing and what the current delivery times of their suppliers are. In other words, it would be possible to know along the entire supply chain, for example when the windows must leave the factory so that they arrive on the construction site at the planned installation time. If those times on the site change, the window manufacturer’s deadline is also shifted, and with this the deadlines of the subcontractors change as well. All this could be effected automatically.

The graphics above illustrate the idea of how as a manufacturer (dark green) you will be connected in the cloud with customers and suppliers (light green). When your customer goes through his ordering process, his system will include the costs of your products, either by linking into your own quoting system (if you allow him to do so) or by mapping your price structure on his system. Your system will do the same with your suppliers and so forth.

The horizontal (purple) path illustrates your investment and maintenance cycle, including upgrades and modernisations of plant and equipment, as discussed further down.

In the realm of manufacturing 4.0 there is a lot of discussion about the IoT (Internet of Things) going on. If all products were electronically equipped so that they at least would know what they are, then they could easily be tracked along the supply chain and through production. The system would always know for example when a product leaves the factory, on which rack it is, on which truck, and where it
has been unloaded - always assuming the corresponding electronics travels with the truck. Of course in this way one could also keep track of the delivery racks.

Block Chain Technology
If everything is so complexly connected and interwoven, then it needs the right contracts, and its compliance has to be monitored. Block Chain technology, initially developed for Bit Coin can help. With every order that is electronically generated, a contract is created. This contract is now generated electronically and runs with the order. This electronic contract is extended in the Block Chain standard with every event concerning the execution of the contract (order, retrieval, (partial) delivery, acceptance, invoice, reminder, payment, etc.). Thus during the whole process and right to the end everything can be looked up without having to search for documents, and all this with extremely high security.

Again, there will have to be standards, to make sure all stakeholders can participate. This is going to take a while, I do not think that is going to happen before 2020, but a lot can happen by 2025. In the meantime, we will have to live with trust and the old forms of contracts.

Continuous Process Improvements and Big Data
As with other industries, machines in the glass industry will increasingly be equipped with electronics that make use of the IoT. Engineers will install more and more sensors to monitor all possible states of the machines and their components. This will allow them to do preventative maintenance of the machines, thus increasing the reliability of the installations.

Glass manufacturers themselves will be able to better monitor production, allowing them for example to detect at an early stage if the defect rate at a particular machine is increasing.

All of this creates a huge heap of data whose collection only makes sense if they are evaluated too. The primary reason for the data collection, and the related analysis, may still be relatively simple, but if we consider what else we could get out of these data, then that is often more complex.

Assume we monitor for each process how many pieces get a scratch. This is a simple counting function. The primary information we want is whether something changes over time. But if it does, then we want to know why it does. If it worsens, then we need to know why so we can intervene correctly. But even if it is improved we want to know why so we can better understand how we can make this last, and potentially use it for other processes too.

Assume you have a process that produces a comparatively large amount of waste, and there is a machine supplier who claims to be better in control of that process and thus produce less waste. Then we still want to know whether that investment would be worthwhile. Now it gets quite complicated. We want to know not only the raw material costs but also the costs of the previous processes up to the one producing waste. Not all pieces have necessarily passed through the same processes at this time. In addition, we must consider the incurring costs of delivery delay, which may also be quite different, depending on whether any delay did arise, and whether it caused any additional costs, be it as a result of additional delivery costs or contractual penalties.
Smart Sensing and Men-Machine Cooperation
An important topic in Industry 4.0 is the cooperation of humans and robots. At present, this is mainly used where part of the work is repetitive and can be done by the robot, while another part is still too complex, too difficult or too expensive for automation. There are already robots, which no longer have to be enclosed with safety fences, but are working directly and, so to speak, hand-to-gripper with humans.

But it has to be said that these are usually robots that can handle relatively small weights (tens of kilos at best). I think that in the glass industry, where heavy pieces with sharp edges need to be moved, it will take some time to address all safety concerns and for the machine manufacturers to offer such solutions. Even then, it might take even longer to find a glass processor to serve as the guinea pig and build such an experimental plant.

Engineering Contractors
Turnkey solutions for plants and software systems for glass processors are currently being offered, but to my knowledge only by manufacturers that supply either most of the components, or where there is close cooperation between the machinery manufacturer and the software company.

What I believe is lacking in the glass industry are engineering contractors who are able to analyse and understand the overall situation of a company, to derive the right procurement recommendations from it, and then to accompany the implementation of the decisions made competently, from contract negotiations to installation. As far as I know, there is no such thing and I am not quite sure whether such a business will be on the market in the medium term.
Conclusions

With the increasing complexity in all aspects of glass processing, manufacturers have to become smart not only on how they produce, but in how they better serve their customers, how they better cooperate with their suppliers, and how they invest, build and upgrade their plants.

It would be the task of the software and machine manufacturers to build unified interfaces, to customers and suppliers as well as to the machines on the floor. It is of course important to ensure the highest possible flexibility. In the near future, there will be a great deal of innovation, and new specifications will be added wherever there is something new. This does not mean that the existing interface standards are no longer valid, but only that they are easily extendable, so that for example new parameters can be specified and incorporated into the interface.

Unified interfaces to machines and plants would also be desirable as mentioned above. However, it will most likely take a while before the bigger machine manufacturers will sit down together to come up with unified specifications.

What is likely to happen in the near future is that providers of machines and services will start providing an availability guarantee. Here, at least as far as the machines are concerned, the IoT comes into play again. Additional sensors on the machines and networking them will allow the machine manufacturers to become aware of problems in a timely manner and to take preventive action before the entire plant comes to a grinding halt.

Thus we have to recognise that although we know the general direction of where this all is going, there are still a lot of open questions. What will the relevant standards be for contracts in Block Chain technology, what is the right technology in regards to the different applications of the IoT, what software and machine interfaces will be standardised and how?

In the meantime we will have to live with what is available. There is no point in waiting for this all to work out and then start the big project that addresses it all. Instead I would recommend to stay agile, to make improvements where it is meaningful now and keep observing what is becoming available and might be helpful in the future.

And in all this, always put your customer at the centre of your deliberations and decisions. You might not be able to deliver for the cheapest price, so make sure you provide best value for money. This can mean better product performance, better quality, better service or better customer experience – or at best all of that.

About the Author

Hans Kull is of Swiss origin, studied Electronics Engineering and Mathematics in Switzerland and did a PhD in Mathematics at the Swiss Federal Institute of Technology (ETH). Hans was developing software for manufacturers for 20 years in Switzerland, before moving to Australia where in 2000 he founded Inmatic, the company he is still running today.

Inmatic has a vast experience in manufacturing software, from order entry for customised products through to production planning, machine data generation and machinery integration.

Hans has written the book “Mass Customisation” (Apress 2015), which explains the new chances and opportunities for manufacturers with the newest innovations in ICT and manufacturing technologies.

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