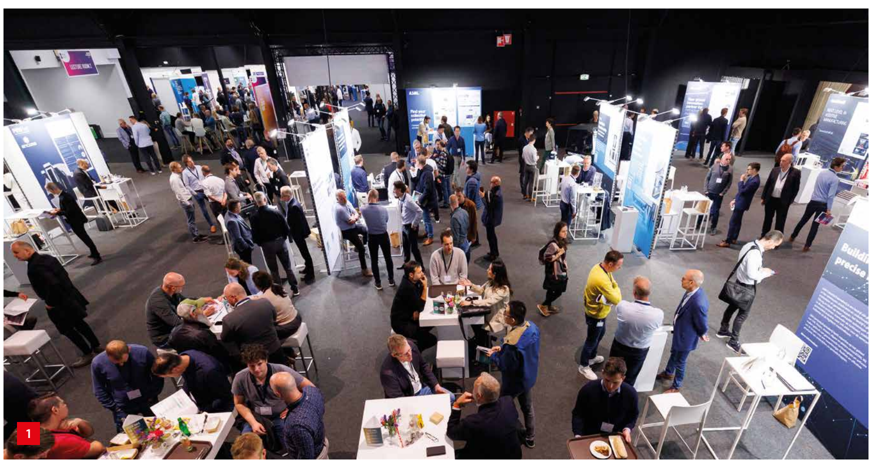
MAKE IT CLEAN

In mid-April, the second edition of the Manufacturing Technology Conference and the fifth edition of the Clean Event were held together, for the first time, at the Koningshof in Veldhoven (NL). Currently, developing a high-quality product involves ever more requirements, complex steps and challenges during the production process, ranging from determining the most suitable manufacturing technique to complying with cleanliness requirements. In order to offer companies better insight into and control over these challenges, the two events joined forces.

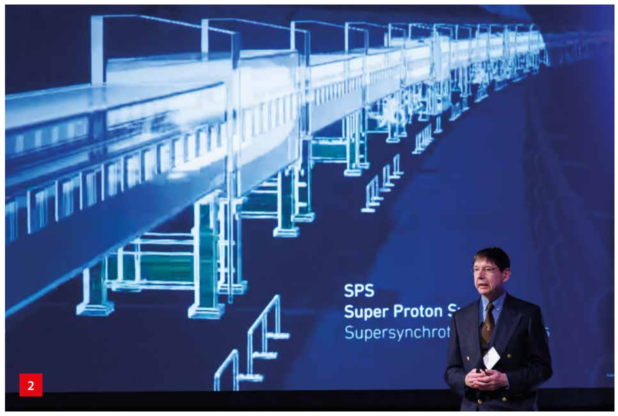
Particular contamination and molecular impurities, even on the scale of a few nanometers, can have disastrous effects on the functioning of a system or machine. Consequently, an increasing number of companies are imposing stricter requirements on the cleanliness of their products, as inadequate cleanliness can have a detrimental impact on product performance. This means that the entire process must be under control, a requirement that extends to OEMs as well as suppliers.

The annual Clean Event, organised by Mikrocentrum, focuses on the control of cleanliness and contamination through the entire manufacturing process, smart product design that facilitates cleanliness, and mitigation of contamination risks during the assembly and packaging processes. This year, the fifth edition featured 70 exhibitors and attracted some 800 visitors.

The Manufacturing Technology Conference brings together engineers from the design and manufacturing industry to share knowledge about manufacturability. Its aim is to increase developers' relevant knowledge and to help them look for possibilities that were previously unknown to them. The conference is organised by the Knowledge Sharing Centre, represented by ASML and Thermo Fisher, in collaboration with Mikrocentrum. This year, for its second edition, the conference was completely sold out, with 100 specialised companies exhibiting on the trade-fair floor (Figure 1).



1 Impression of the Manufacturing Technology Conference exhibition floor. (Photo: Bram Saeys)

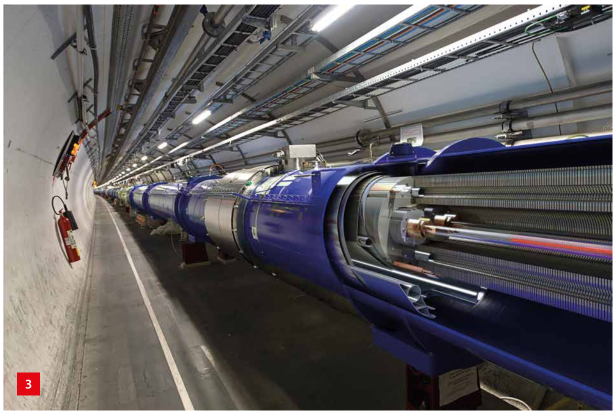


2 Stefano Sgobba of CERN talking about materials for high-vacuum applications in nuclear research facilities such as LHC (Large Hadron Collider) and SPS (Super Proton Synchrotron). (Photo: Bram Saeys)

Materials for high-vacuum applications

The two events shared the opening keynote speech by Stefano Sgobba, head of the Materials, Metrology and NDT (non-destructive testing) section at CERN, the European organisation for nuclear research (Figure 2). He gave an impressive presentation on materials for high-vacuum applications. In modern particle accelerators, stringent requirements are placed on the materials used for the components in the vacuum system, such as the accelerator magnets (Figure 3). Their physical and mechanical properties, machinability, weldability and brazeability are key parameters.

Adequate strength, ductility and magnetic properties at room as well as low temperatures are important factors for the vacuum systems of accelerators working at cryogenic temperatures. In addition, components undergoing baking or activation of non-evaporable getters or those directly exposed to the beam are limited to specific choices of material grades for suitable outgassing and mechanical properties in a large temperature range.



3D cut of the Large Hadron Collider dipole at CERN. For ultra-high vacuum and cryogenic application, suitable materials had to be selected for, e.g., beam pipes, heat-exchanger tubes, magnetic inserts, iron yokes, non-magnetic collars and superconducting coils. (Image: Daniel Dominguez, CERN)

Today, stainless steels are the dominant materials in vacuum systems. Specific requirements in terms of metallurgical processes are necessary in order to obtain adequate purity, inclusion cleanliness and fineness of the microstructure. In many cases these requirements are crucial for guaranteeing the final leak tightness of the vacuum components.

Sgobba presented case studies of material-related failures in accelerator magnets and other components, focusing on welds, and the elimination and prevention of these failures, for which he discussed innovative manufacturing and material examination technologies. In addition, he dwelled on related challenges for the ITER nuclear-fusion reactor, which will contain the world's largest magnet and is currently being constructed in Cadarache, France.

Sgobba ended his presentation with some notable conclusions, including that the prevention of vacuum failures at CERN requires decades of anticipation; materials can seldom be 'off-the-shelf'; high-strength steel grades may be unforgiving and require faultless production and follow-up, starting from the steelmaking; and that stainless steel is not always stainless.

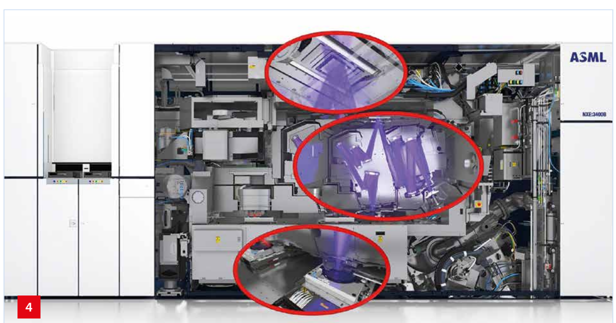
Contamination challenges

Along with this keynote speech from big-science giant CERN, the two events featured various presentations from local high-tech giant ASML. One hands-on example concerned the contamination challenges in the ASML supply chain. After diving into the origin and impact of contamination in the lithography process (Figure 4), supply chain cleanliness/standardisation engineer Steffijn de Koning discussed the translation of these insights into specifications. For this, he made two relevant distinctions.

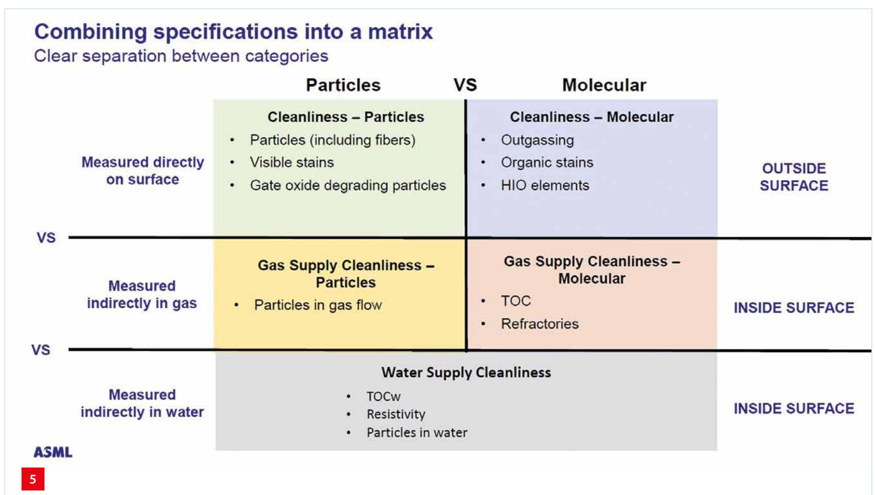
The first distinction is between particular and molecular contamination. Particles are predominantly an issue around the reticle and the wafer, where they can cause defectivity in the chips that are subsequently produced. Molecular contamination, on the other hand, can negatively impact the optics, causing degradation of the mirrors that ultimately leads to a decrease in optics lifetime. Concerning the machine parts where contamination has to be prevented (or removed), another relevant distinction can be made, between inner and outer surfaces. Outside surfaces can be subjected to visual inspection and RGA (residual gas analysis), while inside surfaces can only be inspected through indirect measurements.

To manage the ever-growing contamination challenges in its supply chain, ASML created a new GSA (General Standards of ASML) framework in 2020, featuring a 'manual' for suppliers, GSA 07 9001 ('General Information Cleanliness'), and a number of sub-GSAs referring to the various categories in the matrix of Figure 5. These GSAs define the verification methods (such as visual, bright light, UV-A, RGA and XPS) and acceptable contamination levels for the various types of particular and molecular contamination, broken down across the ASML cleanliness grades (1 to 5).

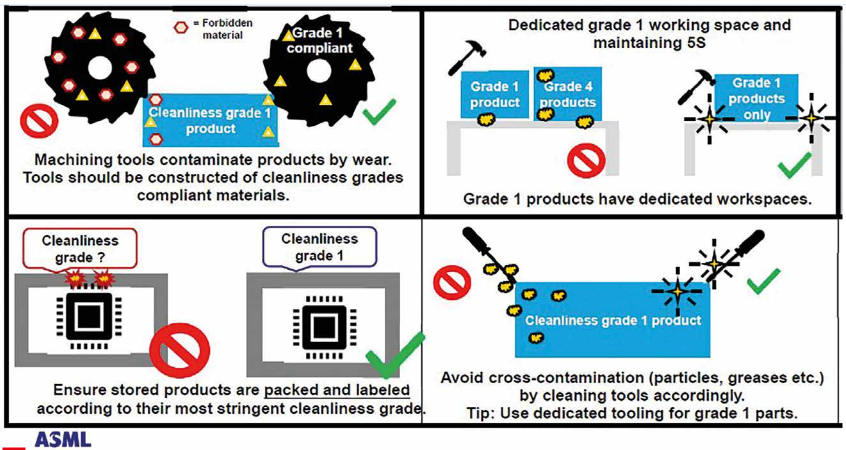
De Koning showed how to use the GSAs from a supplier perspective and concluded with the supply chain challenges ASML faces in the ongoing miniaturisation in



Critical contamination areas in an ASML EUV lithography machine, from top to bottom: reticle, optics, wafer.



Specifications of the various contamination types and their measurement. (HIO = hydrogen-induced outgassing; TOC = total organic contamination)



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Partial snapshot from the ASML quick reference card for clean assembly.

semiconductor manufacturing, driven by Moore's Law. In his opinion, collaboration is the key. "Parts need to be 'ready for cleaning'. To achieve this, the entire supplier community, including n-tiers, needs to take ownership." He illustrated this with the concrete case of a first-tier supplier having problems with removing stains from parts it had obtained. A root cause investigation revealed that the stains originated deep in the supply chain, where milling liquids had not been removed immediately and the resulting stains were subsequently not detected earlier due to a misinterpretation of the relevant GSA.

Better communication and improving the understanding of the GSAs can solve such issues, De Koning concluded. Coming to relief, ASML can help with training, simplifying and translating documentation, and offering n-tier suppliers contact via the first tier involved. As an example, he showed the quick reference cards ASML has compiled for clean manufacturing and clean assembly (Figure 6). After his presentation, these reference cards were in great demand among his audience.

7a


7b

Cleanliness was measured with the Fastmicro Sample Scanner using PMC cards (right).

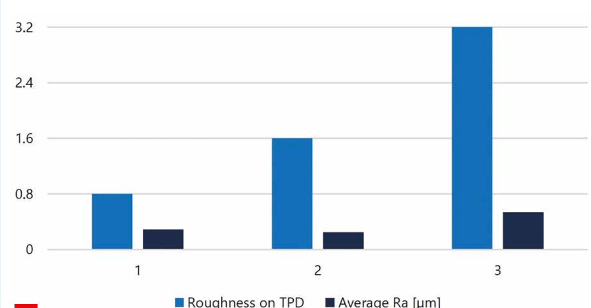
Surface roughness vs. cleanliness

Talking about the supply chain, Hans Cools, manager operations at Meilink Precision Cleaning, discussed the relation between surface roughness and cleanliness, thus making the connection between 'manufacturing' and 'clean'. He presented the results of an investigation conducted by Projectteam Verspanen 4.0 (Project team Machining 4.0), an initiative of the Mikrocentrum High Tech Platform aimed at bringing the machining process to a higher level by investigating the factors that impact the outcome of the process.

Surface roughness, defined as the deviation of a surface's true profile from a straight line, can be represented by various quantities, such as R_a (average), R_p (peak), R_v (valley) and R_z (average of five highest peaks and five lowest valleys). The quantities are calculated from the roughness profile as measured using a profilometer. In the investigation, the PMC (particle measurement card) was used, a kind of sticker that is first applied to a surface and then analysed with the Fastmicro Sample Scanner (Figure 7, see also *Mikroniek* 2021 nr. 6) to determine the number of particles that have been picked up, as an indication of the cleanliness of the surface.

One of the most striking outcomes was that the R_a of the surfaces analysed was on average 7.3 times better than the R_a value prescribed by the TPD (technical product documentation) of the parts concerned (see Figure 8). Suppliers of machined parts are overperforming, was the logical conclusion to be drawn.

When discriminating between the various relevant particle sizes (0.5 / 1 / 5 / 10 μm), a slightly negative correlation was found between the number of smaller particles (0.5 / 1 μm) and the largest particle size (10 μm). This was reflected in the – more relevant – correlation between R_a and PMC count. For the smaller particles this was negative, while for the larger particles it was positive. This may be a kind measurement artefact: with higher surface roughness it may be harder to pick up the smaller particles using the PMC.



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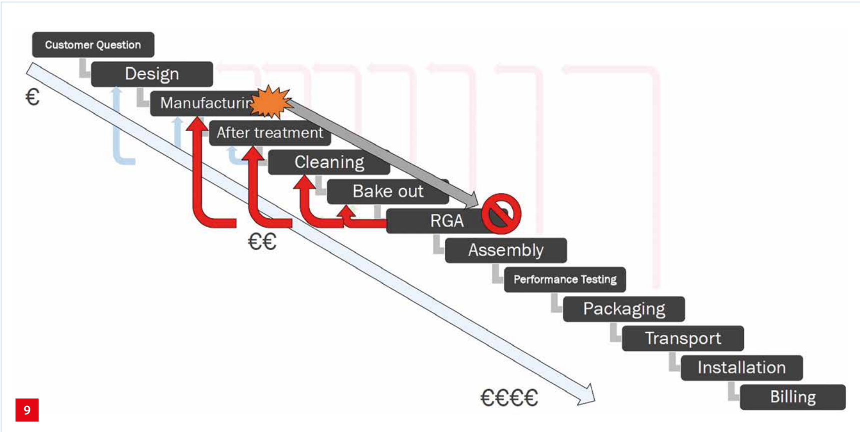
Average achieved R_a as measured vs. the required R_a as specified in the TPD.



9 RGA can be used as a process and engineering improvement tool in the flow of the product creation process. RGA results may provide feedback for clean manufacturing as well as for the subsequent after-treatment, cleaning and bake-out steps.

Closer inspection of the results for the various parts and the way these were produced suggested that the milling strategy that was followed may influence the relation between R_a and cleanliness. In addition, notwithstanding the (expected) strong correlation observed between R_a and R_z, some indication was found that for the strictest cleanliness grades, the R_z value may be a more appropriate requirement than the R_a value to guide the machining process.
Further investigation of these matters will be pursued, Cools announced. He invited suppliers of machined parts to participate in this research.

Contamination analysis and control

Measurement was also the topic of the tech talk by Thom Bijsterbosch, cleanliness engineer at Settels Savenije in Eindhoven (NL). He stated that RGA is not just a vacuum cleanliness assessment tool, but can also be used for process and engineering improvement. After showing how to identify, for example, hydrocarbon contamination by mass number from measured spectra, he turned to the potential sources of contamination, such as operators, tooling, cleaning, coolants, packaging and gloves.

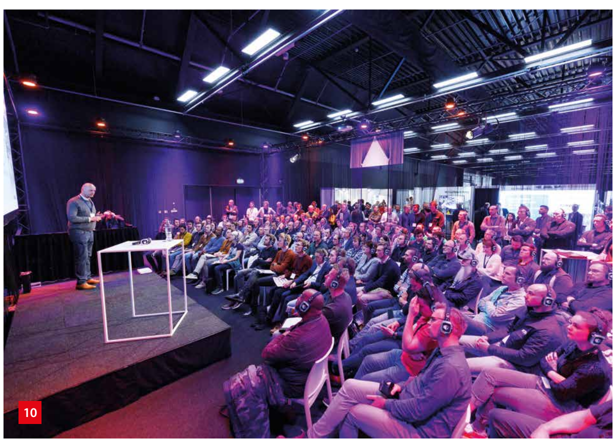
Their impact can be determined in experiments, for example, by changing the cooling or cleaning fluids, or adding or skipping cleaning steps. Moreover, in the overall flow of the product creation process (Figure 9), RGA can provide feedback for clean manufacturing as well as for the subsequent after-treatment, cleaning and bake-out steps. By changing parameters in the production and cleaning process, and comparing the RGA results, the outcome can be optimised. “It’s better to do your research before your product goes out of spec”, Bijsterbosch concluded.

Kasper van den Broek, contamination control architect at VDL ETG in Eindhoven, touched upon similar topics in his presentation on mastering contamination control to enable high-tech applications (Figure 10). Contamination can be prevented by using appropriate materials, clean gases and ensuring parts are properly cleaned, manufactured, assembled and inspected. In other words, for optimal contamination control, the entire lifecycle must be considered. He presented several interesting examples of applications from the semiconductor and analytical industries in the different phases of the lifecycle.

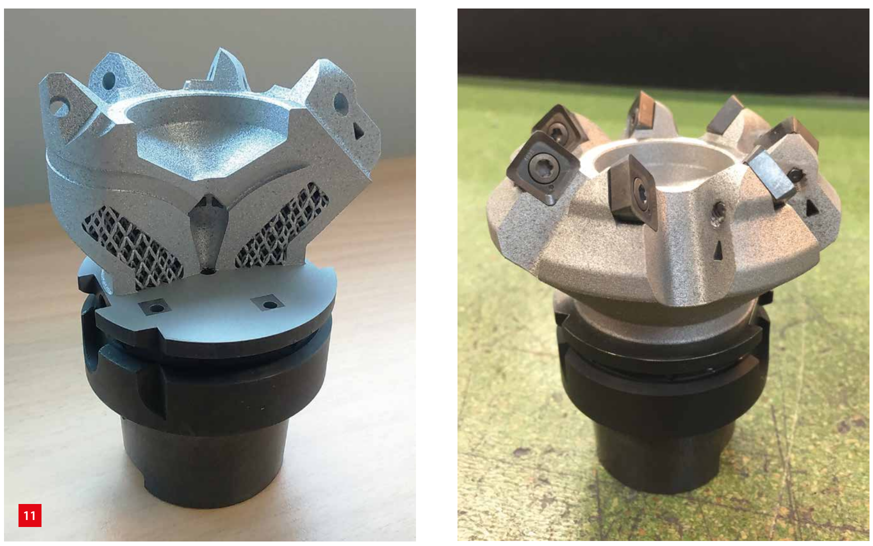
Van den Broek also presented the results of VDL ETG’s ongoing research, in collaboration with Eindhoven University of Technology, in the ACCESS project: Active Contamination Control for Equipment and SubstrateS. The aim is to gain a fundamental understanding of generation, transport and removal of particle contamination, in order to meet the ever-stricter requirements.

AM towards industrial adoption

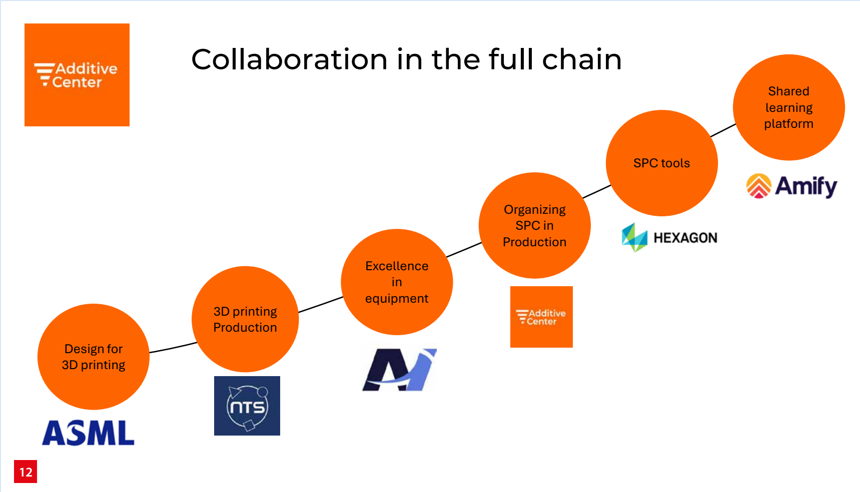
At the MTC, additive manufacturing (AM) was a hot topic. 3D-printing solution providers presented the state of the art, in particular for the printing of metal parts. 3D Systems introduced the concept of hybrid manufacturing, which



10 Kasper van den Broek presenting to a full house about the mastering of contamination control to enable high-tech applications.



11 3D Systems presented examples of tooling that were produced by hybrid manufacturing, combining the machining of the base block and the printing of the tool head.



A full chain for the serial manufacturing of high-tech complex 3D-printed metal parts, from OEM ASML, AM production company NTS and AM machine builder Additive Industries, to SPC implementation partner Additive Center, SPC tool provider Hexagon and, finally, the shared learning platform Amify.

combines AM design freedom with the relatively low cost of subtractive techniques such as milling and turning. An interesting application can be found in the fabrication of tooling (Figure 11), where a cylindrical base block is machined and combined with a tool head that is 3D-printed to optimise, for example, tool shape and cutting fluid flow.

Statistical process control

Ultimately, the adoption of AM in industry requires total control over the complete production process. For this, SPC (statistical process control) is an indispensable tool. When going to series production, 100% part qualification has to be replaced by SPC, using statistical methods to assess part quality. This is because SPC is more effective in large-scale operation, more cost efficient (after the initial set-up) and less time consuming, and – last but not least – SPC provides predictive and preventive insights.

To really make it work, the conventional SPC approach has to be enhanced with process inspection and digital root cause analysis to identify process and environment parameters that impact part quality. In the Masterclass SPC for AM, this approach was further elaborated upon and the full chain (Figure 12) for the serial manufacturing of high-tech complex 3D-printed metal parts was covered, including a shared learning platform provided by Additive Center initiative Amify (Figure 13). This embodies the final conclusion of the masterclass, namely that in addition to collaboration, knowledge sharing is the key to successful AM and SPC implementation.

Activity at the Amify stand on the MTC exhibition floor: assembling the building blocks for a successful AM implementation. (Photo: Bram Saeys)

New name: Manufacturing Knowledge Centre

At the MTC 2024, it was announced that co-organiser Knowledge Sharing Centre (KSC) will now be known as the Manufacturing Knowledge Centre (Figure 14). John Blankendaal, managing director of Brainport Industries, the Dutch high-tech supply chain platform, joined the board. The word 'manufacturing' in the centre's name is crucial, according to KSC chairman Hans Meeske. "The goal is to distribute knowledge through meeting, connecting and sharing, with a focus on manufacturing."

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KSC chairman Hans Meeske and Brainport Industries managing director John Blankendaal disclose the KSC's new name: Manufacturing Knowledge Centre. (Photo: Bram Saeys)

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