Acoustics at Runway West

Manoeuvring aircraft on the ground in an environmentally-friendly and fuel-efficient manner – that is the aim of the project Airport eMove. Operating noise could also be significantly reduced.

Image: Lufthansa LEOS

Towing to the runway

By Katrin Collmar

Loud, fuel-hungry jet engines are already running several minutes before take-off. While taxiing, pilots drive their planes from the departure gate to the take-off position using these powerful engines. They consume kerosene, produce exhaust emissions – and are loud.

However, if the subjects of aircraft and noise are brought up together, the focus is usually on overflight noise. "Hardly anybody is interested in ground-based noise at the airport", says Katja Hein, an engineer who is completing her doctorate at the Institute of Flight Systems and Automatic Control at TU Darmstadt and provides scientific support to the Airport eMove project. In cooperation with Lufthansa, Lufthansa LEOS and Lufthansa Technik, a research team is working on electrifying those processes on the runway that currently consume kerosene.

TaxiBot, for example, is a hybrid tug equipped with two diesel generators and an electric drive for the wheels. In the future, it could be controlled by pilots to tow the aircraft to the runway. "This would save kerosene and could possibly also reduce harmful emissions and noise", says Hein. The researcher's team will investigate its effectiveness. On-site, they compare the different new technologies with the previous standards – and they always have some ear-plugs with them. "The noise is unbearable without them", admits Hein. But how loud is a plane really when it taxies to the runway using its own engines? And how loud is it when being pulled by TaxiBot?

Night time is the best time for Hein and her team to find out as the interference from background noise at Frankfurt Airport is low – thanks to the ban on night flights. Nevertheless, the time available for taking the acoustic measurements is short. They have only 20 minutes because the ban only allows loud engines to run at night with special permission. "The weather conditions also have to be right", explains Hein. The noise of heavy rain can also disrupt the measurements. Once the conditions on Runway West are suitable and the microphones are ready, a plane firstly passes the measurement station under its own power and is then towed by the TaxiBot. "We have been able to notice a clear difference in noise levels even while taking the measurements", says Hein. The measurements provide confirmation: 102 decibels for normal taxiing and 86 decibels for TaxiBotting. This difference is substantial because if the noise level falls by 10 decibels then people subjectively perceive it as being halved.

But this is not sufficient in itself. "We must also investigate how and whether this impacts on the quality of life of people in the region." Therefore, the measurements are being used by Hein to form the basis for a simulation of noise pollution within a radius of about ten kilometres. In addition, she also wants to survey airport personnel, passengers and the local population. "Aircraft and airport noise are hot topics for discussion and we want to be able to make a contribution."

The measurements for the TaxiBot have now been completed. There are now plans to test the eSchlepper and the eTaxi. "We hope to demonstrate in the end that noise at and around airports can be reduced using new technologies."

The author is a scientific journalist.

Information

Institute of Flight Systems and Automatic Control
Katja Hein, M.Sc.
Otto-Berndt-Str. 2, 64287
Darmstadt, Germany
Telephone:
+49(0)6151/16-4951
E-Mail:
hein@fsr.tu-darmstadt.de

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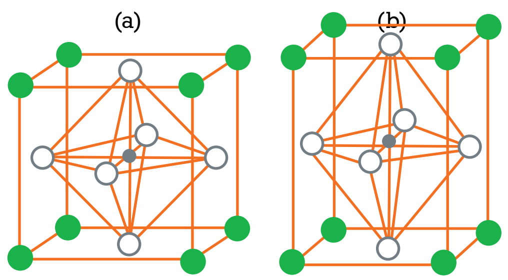
SCIENCE QUARTERLY

TECHNISCHE UNIVERSITÄT DARMSTADT

A future without lead

The Collaborative Research Center SFB 595 at TU Darmstadt has gathered a great deal of knowledge about lead-free piezoelectric ceramics. A status report.



Barium titanate crystals in their cubic, paraelectric form (left) and in their tetragonal, ferroelectric form.

Test to determine the resonance behaviour of a piezoelectric probe.

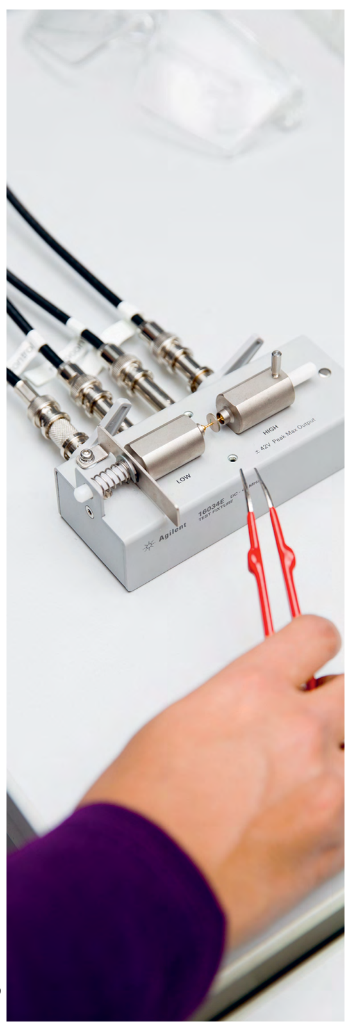


Image: Katrin Binner

By Hildegard Kaulen

When you start up a diesel engine, park your car using a distance control or work with a microscope, you do not necessarily think of piezoelectric ceramics. Yet, it is piezo components that play an essential part in injecting the fuel, positioning the car and adjusting the microscope. Piezo components are generally manufactured from ferroelectric polycrystalline ceramics. There is, however, a problem: All of the standard technical solutions work with materials based on lead zirconium titanate (PZT) or lead magnesium niobate (PMN). Poisonous lead oxide is created in the manufacture and disposal of these ceramics. Therefore, there is considerable environmental pressure to find lead-free alternatives, especially as components made out of lead-based ceramics, in contrast to car batteries, cannot be recycled in closed loop material cycles. More than 20 million injection pumps containing piezo injectors have been fitted up to now in diesel engines alone. "We urgently require lead-free alternatives for these applications", is how Professor Karsten Albe sums up the situation. Albe is heading the Materials Modelling Division and was until recently spokesperson for the now completed Collaborative Research Center (SFB) 595 "Electrical Fatigue in Functional Materials" at TU Darmstadt. The groups collaborating within the SFB have thus been involved in the development and application of alternative lead-free ceramics.

"We will use our experience to develop substitute materials that save on resources."

How do piezoelectric ceramics work? The word "piezo" derives from Greek and means "I press". In 1880, Jaques and Pierre Curie discovered that quartz crystals become charged if they are subjected to pressure. They called this the piezo effect. Conversely, applying an electrical charge can cause the material to expand. This expansion can be used for technical processes in actuators, such as the ones in diesel injection pumps. The benefits offered by piezo actuators are shorter response times and the larger forces they can create. In order to find lead-free alternatives, it is necessary to look more closely at the structure of the PZT-based ceramics. They crystallise to form a perovskite structure (see diagram). The name can be traced back to the mineral perovskite that occurs in nature. In its ideal form, the crystal has a cubic structure. The corners represent the so-called "A positions", while the so-called "B position" is in the centre and oxygen atoms lie at the face centres. In PZT, lead sits at the A position, while zircon or titan occupies the B position. Below the piezoelectric Curie temperature, dipole moments form due to distortions in the ideal perovskite structure. When the material is first made, the internal dipoles group together in domains of random orientation, which is why at first it does not have any piezoelectric properties. An ordered domain structure only forms when the material is polarised in an electrical field with a raised temperature and then cooled again. It then retains a so-called "remnant polarization". It is this effect that gives the material its technically useful piezoelectric properties.

Information

Department of Materials Science
Prof. Dr. rer. nat. Karsten Albe
Jovanka-Bontschits-Straße 2,
64287 Darmstadt, Germany;
Telephone: +49 (0)6151/16-63 74
E-Mail: albe@mm.tu-darmstadt.de
Website of the SFB: www.sfb595.tu-darmstadt.de

Image: Katrin Binner

The doctoral student Virginia Rojas involved in the power synthesis of lead-free materials.

Which options are there for replacing lead in ferroelectric piezoceramics? "Through targeted substitution and doping we have been able to develop new materials with tailor-made properties, opening up new fields of application", explains Albe. In a substitution, a cation is replaced by an equivalent ion. In doping, ions with a different valence are introduced into the crystal. "Irrespective of their lead content, PZT ceramics also have technical limitations, for example, in high temperature applications", continues Albe. When the Curie temperature of the piezoelectric material is exceeded, the piezo effect fails. As lead-free alternatives have higher Curie temperatures, they also offer different potential uses.

What changes have been made? The most important lead-free alternatives contain bismuth sodium titanate or calcium niobate as a base compound. Bismuth is the only non-poisonous heavy metal, while niobium is a transition metal – and both have a similar electron distribution to lead. Working in close cooperation within the SFB, it was ascertained which of these substitutes and dopings were possible and beneficial, as well as what structural, thermodynamic, electromagnetic and electrical properties are produced. "We have all the methods available to us within the SFB to answer these questions", says Karsten Albe, "and we will also use our experience in the future to develop substitute materials that save on resources – for use in energy conversion and storage applications".

They are also investigating how lead-free piezoceramics perform in continuous operation. Here, the collaboration partners analysed relevant fatigue and ageing phenomena. Fatigue describes the degradation of the functional properties under a cyclical load – and is thus dependent on its operation. Ageing describes the irreversible changes in the material's properties that occur over time even when it is not used. Electrical measurements on ageing and fatigue were carried out by, amongst others, Dr. Eva Sapper from the research group headed by Professor Jürgen Rödel. Rödel heads the "Nonmetallic-Inorganic Materials Group" at TU Darmstadt and initiated SFB 595 more than twelve years ago. "Soft piezoceramics are highly elastic but suffer higher losses due to hysteresis", says Sapper. "Hard ceramics are less elastic but are also less susceptible to hysteresis losses. It is possible to control whether a ceramic will be hard or soft through doping. If you dope a ceramic in order to adapt its properties then you have to accept side effects such as fatigue and ageing", explains Sapper. Doping is thus always a compromise. The knowledge gained from the SFB is now being applied in further projects and collaborations.

The author is a scientific journalist with a PhD in biology.

Facts and figures

The Collaborative Research Center "Electrical Fatigue in Functional Materials," funded by the German Research Foundation (DFG), ran for twelve years and concentrated on four areas: synthesis, characterisation, modelling and component properties. The SFB consisted of three transfer projects and a graduate college. There were a total of 28 subprojects. 135 scientists collaborated within the SFB.

Publications:

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Maths and energy policy

Supplying energy is becoming more complex and optimising the distribution grid increasingly more important. Mathematicians at TU Darmstadt are investigating the transport of natural gas.

Special research into gas grids
A Collaborative Research Center (SFB) is a network of outstanding and theoretically focussed researchers at a university funded by the German Research Foundation (DFG) for up to twelve years. The SFB/Transregio variant is a joint application from a number of collaborative universities. In cooperation with six other universities and institutes in Berlin, Erlangen and Duisburg, the TU Darmstadt started work on the SFB/Transregio 154 "Mathematical modelling, simulation and optimisation using the example of gas grids" in October 2014. The project involves 24 mathematicians as subproject leaders, including the TU Darmstadt Professors of Mathematics Herbert Egger, Jens Lang, Marc Pfetsch and Stefan Ulbrich, as well as Pia Domschke, a professorial candidate in Lang's research group, and Michael Schäfer, Professor in the Department of Mechanical Engineering. SFB/Transregio 154 (Spokesperson: Prof. Dr. Alexander Martin, University of Erlangen-Nuremberg, Deputy Spokesperson: Prof. Dr. Jens Lang, TU Darmstadt) offers the ideal opportunity to engage in fundamental mathematical research while simultaneously making a contribution to the change in German energy policy.

Information

Department of Mathematics
Prof. Dr. Jens Lang
Dolivostraße 15,
64293 Darmstadt, Germany
Telephone:
+49 (0)6151/16-23 89
E-Mail: lang@mathematik.tu-darmstadt.de
Webseite of Transregio:
http://trr154.fau.de/

By Uta Neubauer

Hardly anybody gives a thought to the underground network of gas lines when switching on the gas heating, not to mention the mathematics behind gas deliveries. Yet without these calculations, nothing would run at all: Computer programmes are used to calculate the pipes through which the gas should flow and which valves should be opened or closed so that pressure in the pipe will neither fall nor increase too drastically.

Gas distribution is a complicated matter: There are around 750 companies here in Germany that operate sections of the grid and transport natural gas on behalf of the energy suppliers. As a result of the increasing use of renewable energies, this job has become more complicated and also dependent on the weather: Surplus solar and wind electricity needs to be saved in the form of synthetic natural gas or hydrogen and fed into the natural gas grid, just like biogas. As the supplied volumes of gas are always varying, the grid operators constantly need to make decisions to optimise the choice of pipelines to supply with gas. They are gradually reaching the limits of the software they have been using so far. "The control process is becoming ever more dynamic and we thus require new mathematical methods", says Jens Lang, Professor of Mathematics at TU Darmstadt. In autumn 2014, he and colleagues from his department started work together with other colleagues from Berlin, Erlangen and Duisburg in a consortium to create the mathematical basis for modelling, simulating and optimising the grid distribution network of tomorrow.

"The control process is becoming ever more dynamic and we thus require new mathematical methods."

The consortium is not starting from scratch. Many of the academics involved, including Lang, have worked on gas grids for many years and cooperate with energy companies such as E.ON and the gas grid operator Open Grid Europe. The mathematicians base their calculations on the so-called Euler equations developed in the 18th century by the Swiss academic Leonhard Euler, which describe the flow of gas through a pipeline. In order to take into account the processes at compressors, valves and other components, the Euler equations are combined with other formulae to finally develop a mathematical model of the gas grid – a construct based on thousands of equations, each one describing a pipeline or other component.

The model alone does not help the grid operators but it does form the basis for simulations and the subsequent optimisation of the gas distribution. The grid operators primarily want to minimise the use of compressors – which are located about every 100 to 150 kilometres along the pipelines. They require large amounts of energy and are the main cost drivers in gas distribution. The simulation and optimisation calculations are even more complex than the modelling. Millions of equations need to be solved in the shortest time possible. Lang explains: "The simulation of the grid really needs to be completed in a few minutes so that there is still time for the optimisation calculations." However, the model used up until now requires a few hours for the simulation alone. One of the goals is, therefore, to strip down the model. Lang emphasises: "If nothing changes in a pipeline for a certain period of time, e.g. the pressure, flow and temperature of the gas remain constant in a well filled pipeline, I can replace the complicated Euler equations with simpler formulae without any loss in accuracy." However, if the conditions change in this section of the grid because, for example, a compressor starts up, the complex model will need to be used again. The development of these types of simulation processes, which combine different models, is one of the specialist fields of Pia Domschke, a professorial candidate in Lang's research group.

Lang's colleagues Marc Pfetsch and Stefan Ulbrich, also Professors of Mathematics at TU Darmstadt, belong to this group of "optimisers" too. They work on methods designed to calculate the optimal modes of operation for the grid operators: Which valves need to open and close when, and which compressors need to start up when, so that gas can be transported as cheaply but as safely as possible? Efficient optimisation methods are important for answering these questions, whereby the calculated operating mode must not react too sensitively to changes. During day-to-day business, the grid operator must ultimately be able to handle the situation if they need to send more gas than planned through the pipelines at short notice, or if the demand from consumers is more than expected.

Modelling, simulation and optimisation – the mathematicians in Darmstadt have set themselves quite a challenge. In the currently approved funding period of four years, the academics will start by initially mastering small grids. Then, at a later stage, they will integrate real market conditions and the issue of security of supply into their work. Incidentally, it will not only be the gas grid operators who will benefit from the developed mathematical models. They will be of fundamental interest and transferable to other networks such as the mains drinking water supply. That's the great thing about mathematics: it's a universal language.

The author is a scientific journalist with a PhD in chemistry.

Fundamental mathematical research and its practical applications are their passion.

Image: Katrin Binner

Active participation in fire safety

They can help fire fighters orientate themselves more quickly in fires and practice for emergency situations more realistically: scientists supply the digital technology, as well as building simulations.

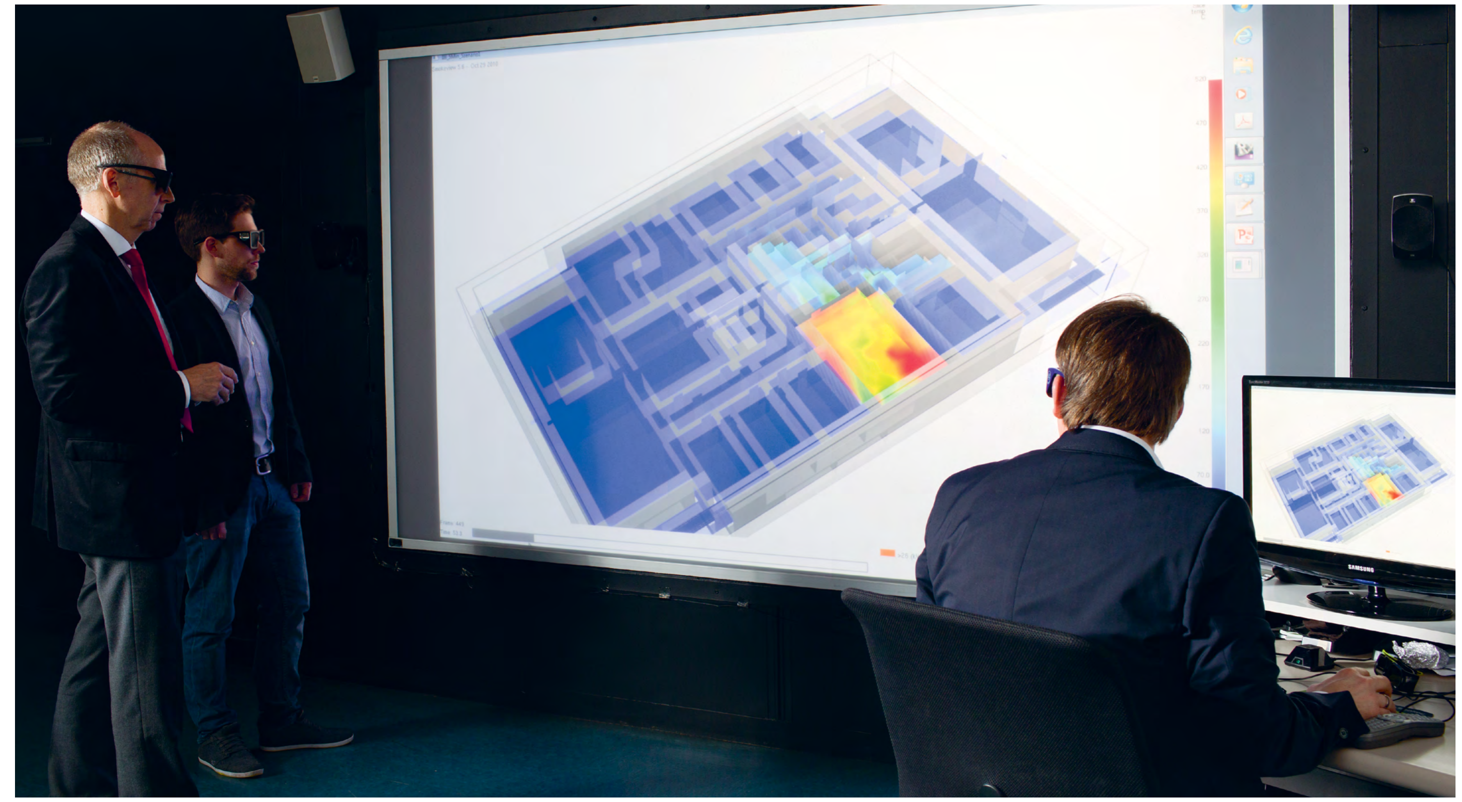

Image: Katrin Binner

A fire simulation in a virtual model of a building: Professor Uwe Rüppel (left) discusses the escape route scenarios with his team.

By Christian Meier

"The construction industry is high-tech" says Uwe Rüppel. For the Darmstadt Professor of Informatics in Civil Engineering, buildings can be partners in communication. High-rise office buildings could, for example, guide fire fighters to the source of the fire. As GPS navigation does not work inside buildings, fire fighters often do not reach where they need to be fast enough. In smoke they have to crawl for safety, instead of being able to move upright and reach their destination more quickly. All too often they come up against a locked door. Finding an alternative route takes valuable time and may cost lives.

A navigation system which works indoors would remedy this situation. Fire fighters would then be able to quickly find their destination by moving upright. This system could also guide maintenance staff from one smoke detector to the next so that they do not miss any. Rüppel's team has already developed demos for indoor navigation systems. Now buildings are set to become even more „intelligent" and actively participate in fire safety. Researchers at the Lichtwiese Campus also aim to find unconventional solutions. They are testing new digital consumer products to see whether they may be appropriate. That's why the researchers from Darmstadt already have the new Google „Tango" tablet with its built-in positioning functionality. Even the video game control device „Kinect" is part of the kit used at this Institute specialising in civil and environmental engineering.

Utilising the full spectrum of digital technology is the approach used by the civil engineers and computer scientists. This multi-method approach is a must for the indoor navigation system: "The more sensors providing it with information, the more precise it will be", explains Rüppel. The team uses radio waves from a variety of sources for positioning. For example, Wi-Fi signals become weaker as the distance to the Wi-Fi router increases. The strength of signal can be used to calculate distance – yet only to an accuracy of one to three meters. Currently under development is the more precise ultra-wideband technology (UWB): this can operate to a precision of around 15 centimetres. The position of a UWB receiver can be determined using the delay times for radio signals from multiple transmitters and the angle between these transmitters and the receiver.

As one network cannot completely cover a whole building, researchers in Darmstadt rely on a combination of networks. So-called RFID (Radio Frequency Identification) tags are useful for remote corners of the building because they do not require any wiring. Textile goods often already carry these RFID tags, which send data as soon as a reading device comes near enough to them. In the future, every single component of a building, such as window frames, pipes or concrete pillars, will be fitted with these tags. The building will thus hold digital information about itself. A concealed gas pipe can therefore be easily identified using an RFID reader, while the strength of the signal will reveal the distance of the RFID tag from the reader.

However, even the most precise positioning is of little use without a digital model of the building. Here too the latest technical developments are also proving useful to researchers. "Everyone is currently talking about BIM", says Rüppel. "BIM" stands for Building Information Modelling – a virtual 3D model of a building. The BIM provides the indoor navigation system with a digital 3D map of the building. At Frankfurt Airport, the researchers from Darmstadt tested a RFID-based guidance system for maintenance work. It should prove even more beneficial for fire safety. "If the emergency services are blocked by a wall, the BIM can tell them if it is a concrete wall or if they can break through it", explains Rüppel. It will also alert them to gas pipelines. An important safety issue also mentioned by Rüppel is that the system only works on the presumption that the virtual model of the building is updated after any renovation work.

"Serious games can be used to train the fire services in putting out fires."

As the BIM can also include fire safety regulation information, such as the minimum width of escape routes, it can already notify architects if they design a corridor that is too narrow. "At the moment, it is sometimes only after a building has been opened that insufficient fire safety measures are identified", emphasises Rüppel. This could now change thanks to BIM. Rüppel's team also aims to adapt his methods for older buildings. Often, no one knows for sure how safe an older building will be in the event of a fire. This can be determined by way of virtual fire simulations – based on BIM.

The virtual model of the building could include data pertinent to fires, such as whether desks are made of wood or metal, which make simulations of fire propagation and smoke development possible. This could help to plan escape routes, according to Rüppel. "The safety of old buildings can thus be determined more accurately and expensive modifications for increasing fire safety could in certain circumstances be avoided." Moreover: "Simulations could help fire fighters to find the source of the fire", says Rüppel. He emphasises that this system could not be used on its own as the basis for making decisions but can provide additional information. There is also a search for unconventional solutions regarding more complex fire simulations. Here, serious games are used to represent situations. A huge projector shows simulations on a surface as large as a laboratory wall, making it possible to act out fire scenarios where research can be conducted into areas such as escape behaviour. "Serious games can be used to train the fire services in putting out fires", says Rüppel. The researchers also use avatars – virtual game characters – to simulate the behaviour of groups of people in the event of a fire. "The BIM makes experiments possible that cannot be carried out in real life", explains Rüppel.

All these things have mostly been visions of the future up to now, but not only due to a lack of technological developments, according to Rüppel. "We must also convince the authorities and fire services", he says. He is optimistic: "Our graduates are bringing these ideas to the wider world".

The author is a science journalist with a PhD in Physics

Building Information Model (BIM)

A BIM is a 3D computer model of a building. BIM is different to established CAD (Computer Aided Design): A BIM represents more than just the geometric form of a building. It also contains semantics, or the meaning and function of individual components. It is thus a functioning simulation of a building that is completed before it is constructed. It knows that a gas pipe is a gas pipe or a window is a window. It also contains information on relationships between components and the whole building. It can show, for example, the effects changes to the plans may have – and not just effects of a technical nature. The BIM will show which trade areas are effected by the changes and the costs these deviations from the plan may entail.

Publications:

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Information

Institute for Numerical Methods and Informatics in Civil Engineering
Prof. Dr.-Ing. Uwe Rüppel
Franziska-Braun-Str. 7
64287 Darmstadt, Germany
Telephone:
+49 (0)6151/16-3444
E-mail:
rueppel@iib.tu-darmstadt.de