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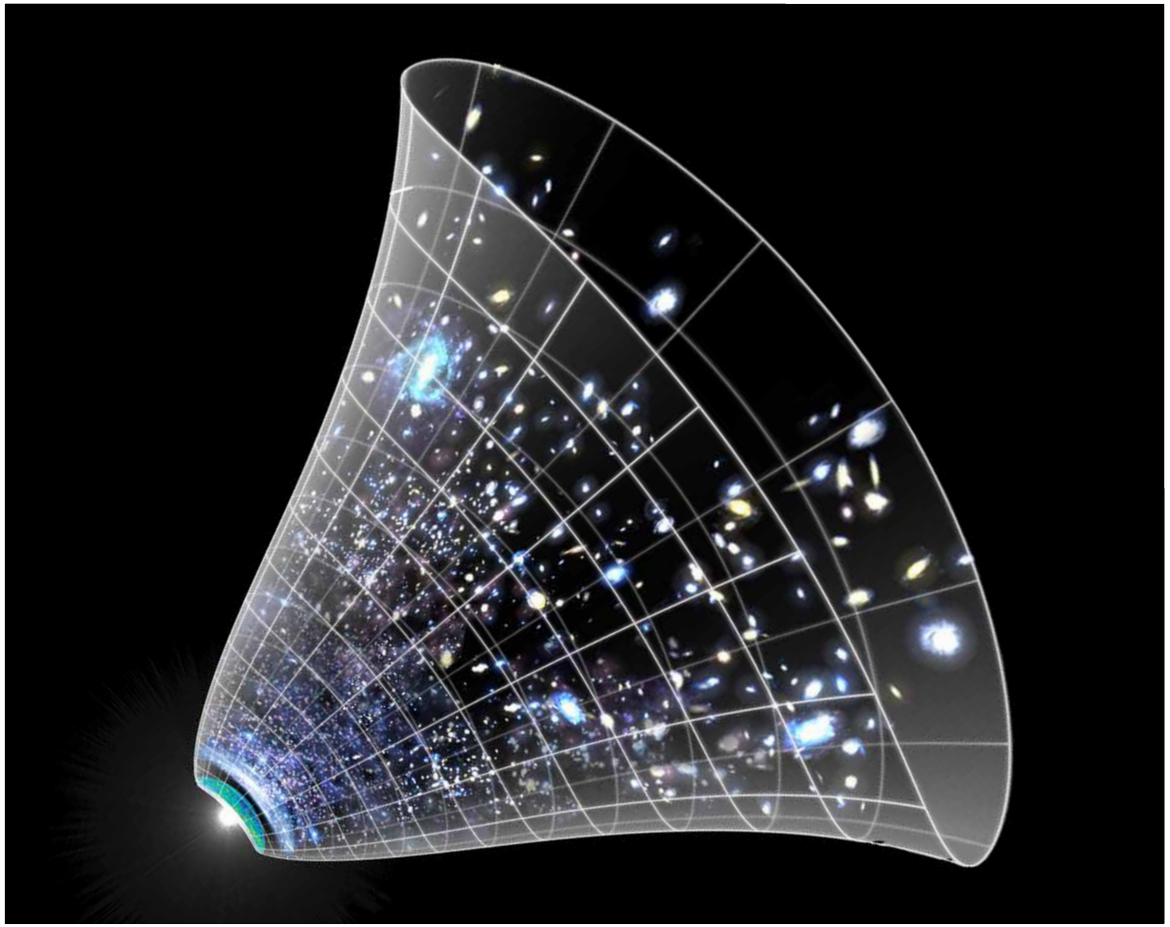
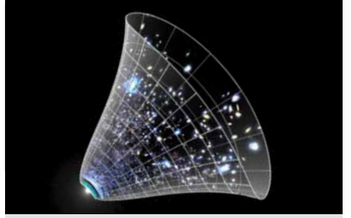


Astrophysics: The Universe in a Supercomputer | **Science and World Politics:** 2022 Annual Review | **Clinician Scientist Programmes:** Seeing Research and Clinical Work as Being Part of the Same Thing | **3D Printing:** The Challenge of the Large Scale | **Urban Transformations:** Gateway to the Future?



Cover: NASA/WMAP Science Team/D. Berry

What looks like a car horn is actually a schematic visualisation of the expansion and structure of the universe since the Big Bang. The explanatory illustration in the inside section on page 17 reveals the insights this provides for astrophysicists.

For Our Values

Science and the humanities in times of war and crises – more than anything else, 2022 has made us aware of our obligations

Looking back over the past year, what conclusions can we draw? This is what you may be asking yourselves at this time, dear readers: it is certainly the question on our minds at the DFG, though with our daily schedules and calendars still packed full, there is less time to pause for reflection than we would like to have.

Foto: DFG/Ausserhofer

The year would seem to require two types of reflection: one that takes in the individual events and developments and another that paints the big picture.

In 2022, the DFG was once again able to achieve important and essential things for science and the humanities in Germany, thereby helping to further strengthen the future viability of our country.

Again, our contribution here started with the regular funding of several tens of thousands of outstanding research projects this year. It is also reflected in our further commitment to establishing framework conditions that are as conducive to research as possible. At the same time, we provided a fresh impetus in areas such as diversity and sustainability in science and the humanities and in the research system. Finally, as 2022 draws to a close, we look forward with great excitement and optimism to the second phase of the Excellence Strategy which has just commenced.

Yet despite all these positive aspects, 2022 was a year in which the DFG too had to respond to war: indeed it was a year in which research and the DFG's own actions were repeatedly taken up with world politics and its crises, at times becoming caught in its grip and its maelstrom.

In the course of this year, the DFG has repeatedly raised its voice and taken a stand on the war and the crises it has provoked. It has done so on its own and also jointly with the other major research organisations, having been the chair of the Alliance of Science Organisations in 2022.

The aim of all of us in taking a stand in this way was not least to defend fundamental values such as freedom, democracy and self-determination – values on which research and worldwide scientific collaboration are themselves founded.

Looking back over the last twelve months in a few selected images which we share with you here, the most striking realisation for me personally – and indeed the prevailing responsibility throughout the year – has been to see just how frequently we have all been called upon to stand up for these values again and again, not just in times of peace, but even more so in times of war and crises.

Professor Dr. Katja Becker
is the President of the DFG.

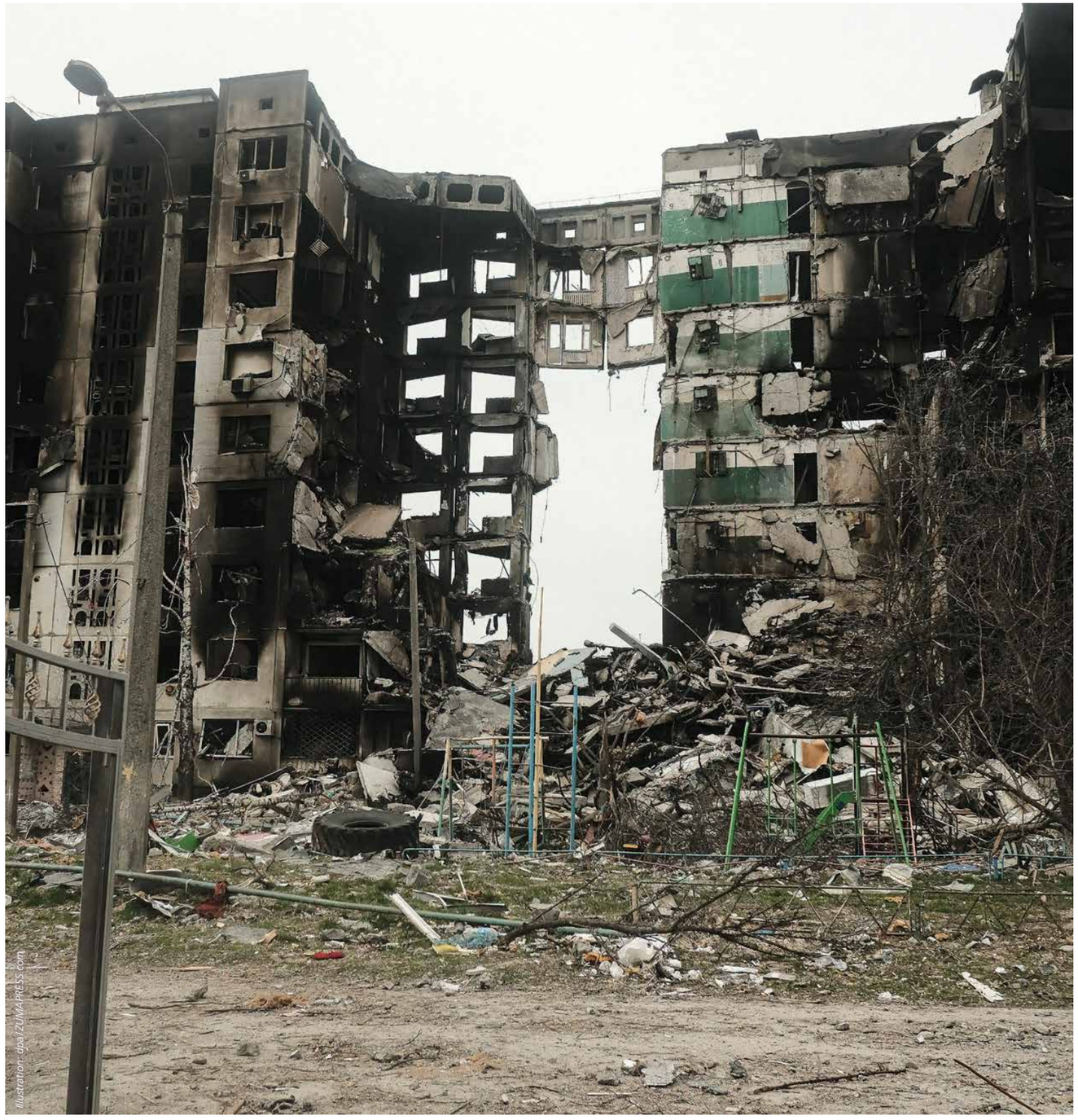


Illustration: dpa/ZUMAPRESS.com

The war was not even a week old before it had inflicted lasting damage on the fruits of decades of collaboration in research. At the beginning of March, in response to the Russian invasion of Ukraine, the DFG suspended all German-Russian research cooperation funded by it at the institutional level. This was a painful step, as it touched on the core of research as a global enterprise and the self-image of those working in it as bridge builders, not least in times of crises. And yet it was a consistent step too, because the Russian attack – as shown here in our picture of Borodianka in the north of Ukraine – is reducing to ruins the very foundations of science and the humanities and research collaboration. At the same time, initial support measures were put into place for Ukrainian researchers leaving their home country, whether by necessity or of their own accord, as well as for those Russian colleagues taking a stand against the war in their homeland. In April, the DFG office in Moscow was forced to close due to pressure from the Russian authorities. At the end of the year, sanctions and aid continue as the war persists, while hope remains that it will one day be over – though no one yet knows when and how that will happen.

Captions on this and the following pages: Marco Finetti

Illustration: dpa / Christophe Gateau

Highs and lows in international collaboration: in the summer, China and Sino-German research cooperation came into focus, too. Here, the question arose for the DFG and the funding recipients as to how to deal with the contradiction between the scientific pursuit of cooperation and excellence on the one hand and the Chinese desire to exercise political control on the other. In autumn, there was concern in research with regard to Iran, too – regarded by many as one the most promising research partners of the future: here, the regime responded with brute force to protests against moral policing and paternalism that erupted at universities in particular. Despite the crises, however, there were encouraging signs of solidarity and effective bridge-building within the international research community, too. For the DFG, this included increasingly close contacts with other Asian partners, trusting collaboration with Polish partner organisations, the growing European Research Area with its diverse range of potential for higher education institutions in particular, and also the annual meeting of the Global Research Council – the worldwide association of research funding organisations. Alliances of this nature are urgently needed: after all, global challenges such as climate change can only be overcome through collaborative efforts. Our picture shows the flags of the participating states at the UN Climate Summit COP27 in November in Sharm El-Sheikh, Egypt.

The pandemic dictated our thoughts and actions for two long years. This year, it has no longer consistently dominated the news cycle and agendas, with the war pushing even the virus out of the head lines at times. The coronavirus and the pandemic have not disappeared, of course. It is certainly still a part of people's day-to-day lives, making them increasingly exhausted and often irritated as further debate arises regarding the compulsory wearing of masks on local public transport, for example. Our picture was taken in Hanover. And it is still very much part of the day-to-day fabric of science and the humanities, too. Since the outbreak of the pandemic, the DFG has launched well over 100 research projects on all facets of the pandemic through various calls for proposals, whether of a broad, overarching nature or focusing on very specific topics. These projects have continued to generate a wealth of new and important findings in the past year, whether fundamental insights in medicine and biology or an understanding of the political, economic, cultural and social dimensions and consequences. The Interdisciplinary Commission for Pandemic Research took stock of the situation in a paper entitled "Pandemic Preparedness", showing from the perspective of its members from all research areas what gaps in knowledge and action the pandemic has brought to light and what we can learn from this to be better prepared for future pandemics. After all, they are bound to happen again – and this is by no means a platitude.

Illustration: dpa / Ole Spata

Drastically rising energy prices, not least a consequence of the war, and an unusually high level of inflation in autumn meant a lot of people had a bleak view of the upcoming winter. The government put together relief packages worth billions, with new technologies aimed at helping avoid impending supply bottlenecks: our picture shows the assembly of gas pipelines for the planned LNG floating terminal in Brunsbüttel. But the fear of an energy crisis remained. The research community was worried about the potential impact, too: it could potentially set back energy-intensive branches of research by years and result in universities having to suffer another winter of lockdowns after the pandemic. Higher education institutions sought to counteract these developments by means of hastily introduced energy-saving measures and prioritisations in research and theory. Additional government support was needed to avert serious damage, however. And it was forthcoming. As it had previously done so in the wake of the Russian attack on Ukraine in spring, the Alliance of Science Organisations stated the positions and concerns of research and articulated these to policymakers. As a result, research institutions and research facilities were included in the emergency aid measures, with price caps on gas, district heating and electricity also applying to them, while a hardship fund was also set up for non-university research. The situation remained difficult, however, and negotiations on hardship provisions continued. Winter was certainly on its way – and was to be weaponised in Ukraine.

Illustration: dpa/Marcus Brandt

Reinforcing Indo-German Collaboration

DFG Secretary General Heide Ahrens visits India / Discussions focused on strengthening Indo-German cooperation

Illustration: DFG

A DFG Delegation headed by Dr. Heide Ahrens, DFG Secretary General, visited New Delhi, India, in October 2022. The programme included visits to reputed scientific institutes like IIT Delhi, meetings with German organizations as well as funding organizations such as Department of Science and Technology (DST) and others, Ministry of Science and Technology. In a meeting with Dr. Srivari Chandrashekhar, Secretary, Department of Science and Technology and his team from the International Cooperation Department, the delegation discussed matters of mutual interest to strengthen the bilateral cooperation between the two organizations. Mr. R. Madhan, Director Indo-German Science and Technology Center (IGSTC) and former Science Counsellor at the Indian Embassy in Berlin gave an insight into the structure and activities of the center in India. On October 19th, the DFG hosted a Interner Linknetworking dinner-reception at the The Imperial, New Delhi to celebrate 15 years of operations of the DFG Office India. During the whole visit, the interactions showed the great potential for further activities and the continued support for Indo-German research collaborations.

www.dfg.de/en/dfg_profile/head_office/dfg_abroad/india/reports/2022/221129_ahrens_visits_india

Strengthening Pandemic Preparedness

Commission for Pandemic Research identifies gaps in knowledge and action during the coronavirus pandemic

The DFG's Interdisciplinary Commission for Pandemic Research has evaluated its findings and experience gained from the coronavirus pandemic to date. Made up of 21 members drawn from all research areas, the statutory body recently published a statement in which it sets out its conclusions with a view to ensuring future pandemic preparedness. In a total of 17 Lessons Learned, gaps in knowledge and action are identified along with measures to be taken from the perspective of the sciences and humanities. The Lessons Learned are aimed at politicians and administrators as well as research organisations, research funders, media representatives and researchers.

"The coronavirus pandemic has occurred during an era of multiple complex global crises," said DFG President Professor Dr. Katja Becker, Chair of the Commission for Pandemic Research. "At a moment such as this, scientifically secured knowledge is of particular value, as are research structures and resources. By presenting this statement, our aim is to strengthen future pandemic preparedness by incorporating perspectives from all research disciplines. It is precisely this interdisciplinary dialogue on the needs of pandemic-related research and those of the sciences and the humanities in general that we have found to be especially beneficial within the Commission."

"The statement published by the DFG Commission on Pandemic Research is a synopsis of observations and findings arrived at during the various phases of the ongoing pandemic from the perspective of the researchers involved. It makes no claim to fully represent the diverse range of research and funding activities being pursued within the German research system and beyond," said DFG Vice President Professor Dr. Britta Siegmund, member of the Commission. "Instead, specific concrete examples are provided of the Lessons Learned. In addition, the statement outlines further research needs and sets out how the framework conditions are to be developed to ensure that effective action is taken on the recommendations made."

www.dfg.de/en/service/press/press_releases/2022/press_release_no_37

Third Polish-German Science Meeting

DFG and partner organisations FNP and NCN underline the central importance of German-Polish cooperation / Close dialogue on current crises

The third Polish-German Science Meeting held in Berlin at the end of October focused mainly on the current global political crises and their impact on science and research in the two countries, as well as potential response strategies. Attended by representatives of 17 research institutions and funding organisations from the two states, the two-day meeting was organised by the DFG and its two Polish partner organisations, the Foundation for Polish Science (FNP) and the National Science Centre (NCN). All three institutions stressed the crucial importance of bilateral cooperation, especially in the face of the climate crisis, the coronavirus pandemic and the war against Ukraine.

Illustration: DFG / Bildschön, Peter Lorenz

On the second day of the conference, discussion centred in particular on the activities being pursued by the individual Polish and German institutions in support of Ukraine. Here it emerged clearly once again that cross-border cooperation offers enormous potential in tackling crises.

www.dfg.de/en/service/press/press_releases/2022/press_release_no_44

Networking, Advice and Discussions

GAIN conference in Bonn with Talent Fair and around 400 participants, including 250 postdocs

Everything at GAIN22 from 2 to 4 September revolved around Germany as a research hub. Jointly organised by the German Academic Exchange Service (DAAD), the Alexander von Humboldt Foundation (AvH) and the DFG, the event provided careers advice for researchers in the postdoc phase. For the 400 participants, including 250 postdocs, the focus was on the opportunities available to postdocs in the German research system, along with individual counselling at the traditional Talent Fair.

Illustration: Michael Jordan

A new feature on this occasion: for the first time in over 20 years, GAIN22 didn't take place in the USA but in Bonn. As such, it was primarily aimed at researchers from Germany who are currently mainly based outside Germany in other European countries and in some cases Asia and Africa. The target group of German researchers working in North America was not neglected, however, because a digital workshop event was also arranged following the in-person event.

www.dfg.de/en/service/press/press_releases/2022/press_release_no_35

www.gain-network.org/en/annual-gain-conference

Rembert Unterstell

Illustration: Wiebke Peltz

„Seeing Research and Clinical Work as Being Part of the Same Thing“

Research combined with clinical advanced training: the DFG's new Clinician Scientist programmes provide a structural impetus for German university medicine. What has been achieved so far – and what remains to be done. An interview with Vice President Britta Siegmund

german research: *Professor Siegmund, university hospitals are at breaking point and operating in crisis mode. There was even a risk of collapse during the coronavirus pandemic. Is there still any significant scope for clinician scientists to conduct research at all?*

Siegmund: Clinician scientists funded through our programmes have continued to retain freedom during periods of crisis too, with very few exceptions. But outside of the programmes and the temporary substitute positions, it's virtually impossible to release people: firstly because the coronavirus pandemic has had a considerable impact on the day-to-day routine at hospitals, and secondly there are enormous economic constraints at the moment.

Despite all these burdens, ten more programmes were approved in the summer that focus on research topics ranging from autoimmune and infectious diseases to civilisation disease and age-associated illness. What overarching expectations do you have of these?

I've observed the emergence and development of Clinician Scientist programmes for twelve years now. The crucial point to bear in mind here is that development through to implementation at medical faculties and university hospitals actually takes years – and this then leads to an increased demand for such programmes. After all, they do indeed provide scope for action and demonstrate that scientific research and clinical training can indeed be combined in a structured way. This process ultimately brings about a cultural change – and the expectation is that in the long run this cultural change will take effect across the board.

But before this cultural change can take place, the first problem to be tackled is the compatibility of clinical activity and research in day-to-day routine. Would it be wrong to assume that "protected research time" ultimately depends on the resources available to large medical centres versus small ones?

In the programmes where 50 percent of the positions are co-financed by the DFG, this protected time is a requirement for such programmes to work in the first place. But of course: the more people there are working at a hospital, the easier it is to implement the system in the work schedule. By the way, I'm not so keen on the term "compatibility" in this connection, although it is commonly used. With our Clinician Scientist programmes, we're ultimately doing something that actually goes back to the origins of university medicine, namely letting younger, committed doctors do clinical work: they pick up on questions that arise in day-to-day hospital routine and pursue them in greater depth based on clinical trials or in the lab. These questions only arise if you're involved in both areas and are familiar with both sides. That's why it's so important to see research and hospital work as being part of the same thing.

There are currently some 400 doctors engaged in active research who receive funding during their specialist training. What has been achieved to date – and what still remains to be done?

What has been achieved to date is that these programmes are essentially available nationwide. That sounds good and has been a huge step forward. Nonetheless, if you take a closer look at the numbers, you'll see that there are a handful of university hospitals with a lot of programmes and many more with only a limited number. According to figures provided by the German Science and Humanities Council (Wissenschaftsrat, WR), it is estimated that these programmes are followed by 7 percent of junior doctors in further training; in Berlin we think it's now almost 10 percent. The task now will be to develop the programmes further and integrate them into university medicine as a permanent structure in the long term. This is something we haven't managed to achieve yet.

There seems to be a need for a new job profile, too. The Clinician Scientist stands for high-quality, interdisciplinary research that has nothing in common with the pro forma research of yesteryear. Isn't that simply a matter of common sense?

At university hospitals with a strong research profile: yes – nowadays it's absolutely clear and visible that research is no longer possible without these programmes. In the last 20 years we've seen a lot of changes,

Professor Dr. med. Britta Siegmund …

… is Director of the Medical Clinic for Gastroenterology, Infectiology and Rheumatology at Charité – Universitätsmedizin Berlin, where she is also head of the Charité-Center for Internal Medicine with Gastroenterology and Nephrology. Her research focus is chronic inflammatory bowel diseases. Since 2019, she has been Vice President of the DFG and Chair of the DFG Senate Commission on Key Questions in Clinical Research.

www.charite.de/en/service/person_detail/person/address_detail/prof_dr_britta_siegmund

The DFG Clinician Scientist Programmes …

… originated from an initiative of the Senate Commission on Key Questions in Clinical Research, which recommended the "establishment of an integrated research and continuing education programme for clinician scientists parallel to medical specialist training" in 2015. The new funding programme came into existence as a result of the impending shortage of research physicians in university medicine. In the course of the first programme call in 2018, 13 projects nationwide were accepted for funding after international review, with another 10 programmes being approved in summer 2022. As of the end of 2022, more than 400 doctors actively involved in research are receiving temporary funding at 22 medical faculties. A total of 35 out of 39 medical faculties in Germany participated.

including positive ones, for example the fact that it's no longer desirable to be able to do research in the evenings only – that there have to be regulated structures to provide freedom for the next generation. That's definitely something we need, too! It's the only way to develop university medicine in Germany in the long term.

Freedom, laboratory space and funding are one thing, but mentors in the day-to-day running of the hospital are another. Do you accept the criticism when physicians from abroad complain that German university medicine has a mentoring problem?
In Germany we have a completely different system of further education (residency, fellowship) from that of our European neighbours, as well as the UK and the USA, where advanced medical training takes place in very structured programmes, i.e. the residency. Things have improved vastly in Germany and are now much more structured than they used to be 20 years ago – I can say that from my own experience. Mentoring requirements are clearly built into programmes and are assessed. The majority of the programmes involve a clinical mentor and scientific mentor who are closely linked to the individuals over three years in a phase that we shouldn't forget is highly formative. Subject-specific dialogue and personal supervision remain important factors, as does moral support.

Nevertheless, the impression remains that pursuing a career in university medicine is a difficult undertaking …
… I see two aspects here: the current generation of upcoming doctors expect much more reliable career paths than were expected 20 years ago. That's a change. The second point is that there has been a shift in the kind of job people are striving for in university medicine. Many scientifically active and talented early-career physicians don't necessarily want to take up a professorship, which would involve more bureaucratic activities. Many would rather have a clinical niche where they can pursue research into a scientific topic, too. We've only had this type of structure to a very limited extent to date however, for example a Heisenberg professorship or a professorship linked to a Clinical Research Unit. The German system doesn't yet provide for this. There has to be a shift in terms of the positions people can aspire to in university medicine so as to be able to offer real prospects for committed individuals.

Advanced training in medicine is regulated in many respects in terms of time requirements. What is the situation regarding the extent to which state medical associations recognise time spent on research as counting towards further training?
That's an important point. A few state medical associations do recognise up to three years spent doing a Clinician Scientist programme as counting fully towards the period of advanced training. That makes sense: after all, the projects and their subject matter are closely related to the content of advanced training. But there are other medical associations (Landesärztekammern) that still only recognise a small amount of research time as counting towards training requirements. A lot of persuasion will be required here.

A striking feature of central Berlin: the Charité with its renovated ward block.

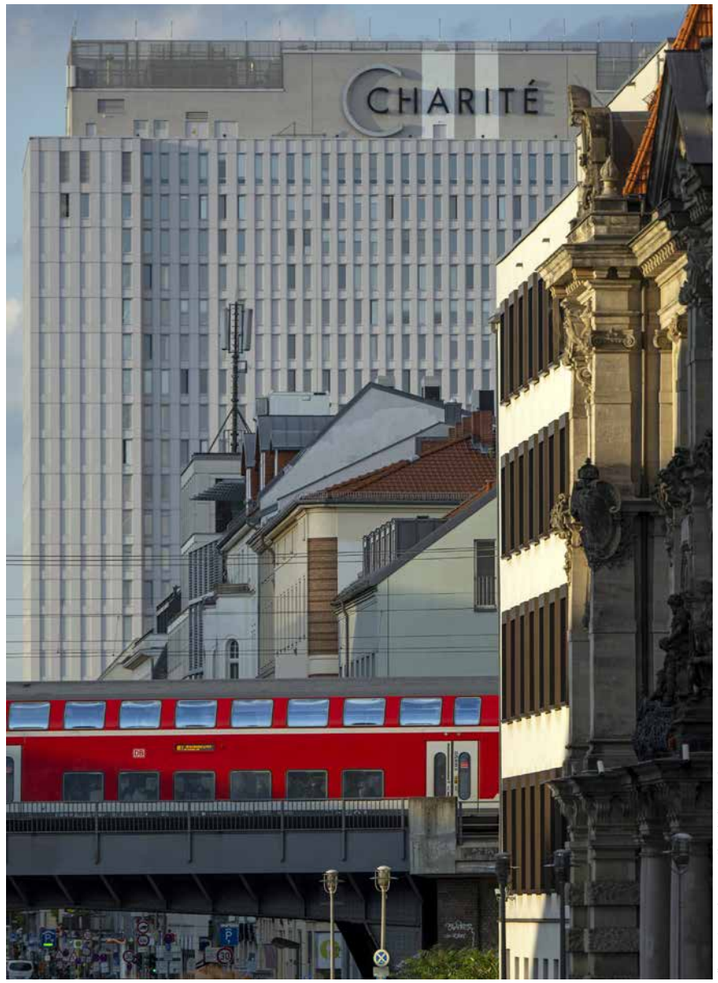


Illustration: dpa | Monika Skolimowska

The DFG programmes focus on early career phases, while the BMBF's Advanced Clinician Scientist programmes are geared towards later career phases. Are these funding programmes sufficient?
They're vital cornerstones and send out an important signal to university medicine. The communities are responding to this, and further work now needs to be done. But to answer your question: no, I don't think it is enough. The challenge is how to develop these programmes further and continue to fund them when the temporary funding expires. I'd like to see systematic funding, perhaps through cross-funding options, too. In terms of the Advanced Programme that has just been set up, we don't yet know how that will develop. After all, when the funding expires, it won't necessarily lead to the creation of a professorship. More flexibility and more models will be needed – I think there are more jobs to aspire to in university medicine than many people realise.

When the first Clinician Scientist grants expire after six years in 2023, what can the university hospitals themselves do to make them permanent on a local basis?
That depends on the hospitals themselves: after all, they've all committed to consolidation. To what extent this will succeed remains to be seen. It's certainly a considerable challenge in the current situation given the economically precarious environment. We can only hope that the university hospitals are able to find the funds and that the federal states support them in doing so.

You talk about commitment among policymakers. Will these programmes work at all without permanent funding being provided by the federal states?
I don't think so! It would be good if every university hospital were to receive a certain proportion of basic funding for these programmes – based on evidence of certain quality characteristics of course. Then, as an option – linked to this basic structure – sub-programmes geared towards specific subjects could be tied in via other funding.

Illustration: U Münster/ Erk Wibberg

Advanced medical training and a career involving work both in the lab and the hospital: this is what the "clinician scientist" stands for, shown here in a symbolic image provided by the University Medicine Münster.

Here in Berlin, our experience of this has been very positive with the "BIH Charité Clinician Scientist Programme".

What will be the main focus in the future in terms of the further development of university medicine?
Those working in university medicine must come to an agreement as to what role they believe Germany should play in medicine and the life sciences in the long term. If we want to be internationally competitive – both in translational and clinical research – we need medical professionals who are trained accordingly. This can only be achieved by means of structured programmes and in subject-specific dialogue with other countries. Only if these framework conditions are provided will German university medicine be able to remain internationally visible and competitive in the long term.

Thank you very much for talking to us.

Interview: Dr. Rembert Unterstell,
Publishing Executive Editor of *german research*.

Volker Springel

The Universe in a Supercomputer

How did our galaxies form and how did they evolve? Based on new simulation models and using the methods of numerical cosmology, astrophysicists are seeking to shed light on the darkness. The starting point: the immediate aftermath of the Big Bang

The sun is just one of almost 100 billion stars in our home galaxy, the Milky Way. With the naked eye, however, we can only see a few of the nearest stars in our immediate vicinity, and unfortunately the light pollution in our cities means that many people have never seen the band of the Milky Way for themselves in the night sky.

But the Milky Way is far from being the only galaxy in the universe: billions of such islands of stars can be detected using modern telescopes. Over 100 years ago, US astronomer Edwin Hubble (1889–1953) introduced a classification of their shapes that is still in use today. A rough distinction is drawn between disc galaxies in which the stars move in circular orbits around the centre, and elliptical galaxies in which the stars move in disordered orbits. Since there is a huge amount of space between the stars, collisions between them virtually never occur.

Edwin Hubble also discovered that galaxies appear to be moving away from us – and the further away they are, the faster they appear to recede. This phenomenon, known as Hubble's law, provided the first decisive indication that space itself is expanding, similar to the dough of a sultana loaf that rises profusely, where we might imagine the sultanas to be the galaxies. The sultanas do not move relative to the dough, but they all move further apart from one other; and the further apart they are from each other, the faster they move.

In recent decades, astronomers have conducted systematic sky surveys that have allowed them to determine not only the angular position but also the distance of hundreds of thousands of galaxies. The resulting three-dimensional maps of the galaxy distribution held another major surprise: the galaxies are by no means randomly distributed in space, but are arranged in a net-like structure in which they are concentrated along thread-like chains that converge in nodes and span huge voids.

Where does this cosmic web come from? Why do galaxies exist at all in the shapes, forms and sizes observed? And when and how did the galaxies come into existence? These are just some of the fundamental questions that cosmology seeks to answer about galaxy formation.

If we virtually reverse the expansion of space and extrapolate

What looks like a modern work of art is in fact a visualisation of cosmic structures: the gravitationally collapsed pieces of dark matter (orange and white) are embedded in a complex cosmic web of dark matter. Incoming gas is heated in hydrodynamic shock waves (blue and white areas).

Illustration: Illustris TNG Collaboration

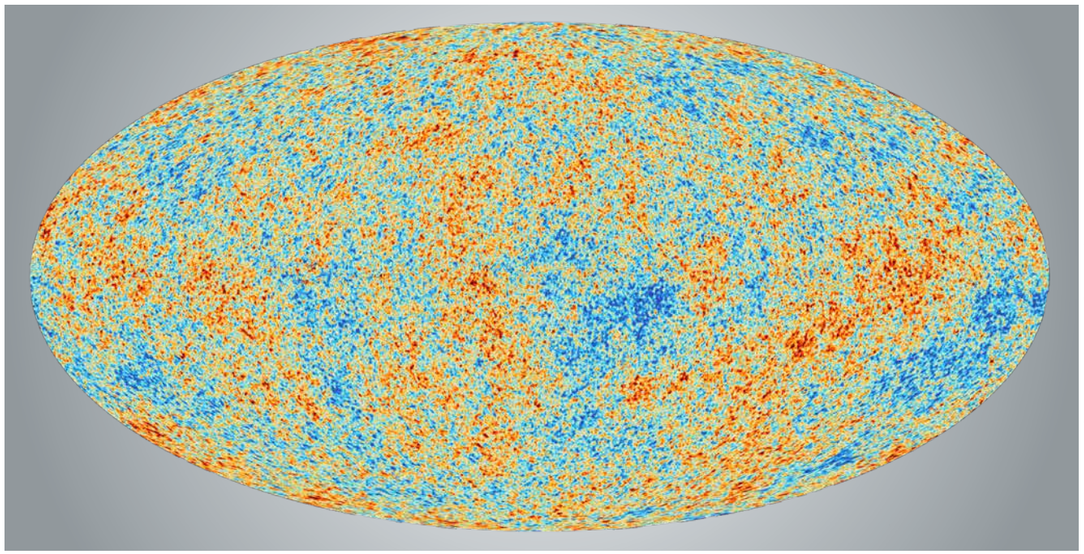


Illustration: European Space Agency, Planck Collaboration

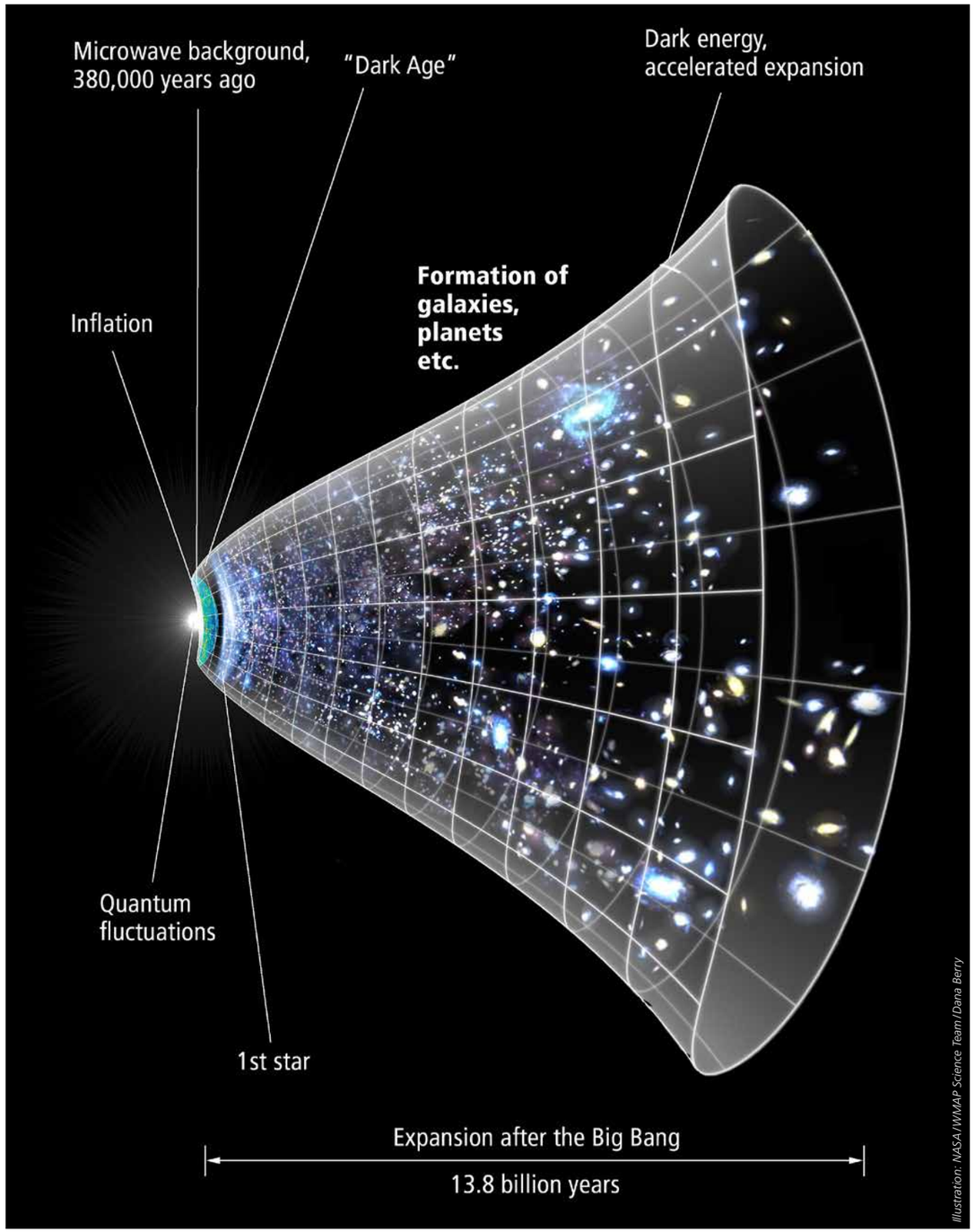


Illustration: NASA/WMAP Science Team/Dana Berry

Top: The ESA's Planck satellite observed the cosmic microwave background with unprecedented accuracy from 2009 to 2013. This map of the whole sky shows tiny temperature variations in the thermal radiation that reaches us from all directions. Right: Schematic representation of the spatial expansion and structural evolution of the universe since the Big Bang. The initial state approximately 380,000 years after the Big Bang (greenish area) can be observed directly in the cosmic microwave background.

back in time – i.e. make an estimate based on the development trends we can observe now – we quickly come to the conclusion that the universe must have begun in an incredibly dense, hot state. This is the Big Bang, which occurred some 13–14 billion years ago. In fact it is still possible to see residual heat radiation from this time, the so-called cosmic microwave background. This consists of photons that were released when the universe cooled down to about 4,000 degrees, 380,000 years after the Big Bang.

In the hotter state before this point, there was still an opaque plasma, but now hydrogen and helium nuclei were able to capture their electrons and form a neutral gas, allowing thermal radiation to move freely. Since that time, however, the expansion of space has stretched the wavelengths of the photons by a little more than a factor of 1,000, so today the temperature of the radiation is only 2.73° Kelvin (-270.42° Celsius) above absolute zero (-273.15° Celsius).

Satellites such as the European Space Agency's (ESA) microwave space telescope Planck have measured this radiation very precisely, in particular its tiny temperature variations of only about one ten-thousandth around the mean temperature. Based on these statistical properties it is possible to make various precise assumptions about the composition of the universe and then compare these with measurements.

The conclusions of such a comparison take us to the very limits of what we as human beings are able to grasp based on our experience: only about 5 percent of the energy/matter content of the universe is made of normal matter, i.e. the chemical elements of the periodic table. About 25 percent is so-called dark matter, which is assumed to be an as yet unidentified, extremely weakly interacting elementary particle, and a good 70 percent is present as dark energy. The latter counteracts normal gravity, which consistently acts as a brake on the expansion of space: but dark energy has been making the universe expand at an accelerated rate over the last five billion years. The true physical nature of dark matter and dark energy is one of the most fundamental puzzles of modern physics.

Can galaxies like the ones we observe actually form in such a curiously composed universe? Together with my working group and the international research community, I am trying to find answers to

this using the methods of numerical cosmology. The starting point here is the state of the universe shortly after the Big Bang, as observed in the microwave background. At that time, stars and galaxies did not yet exist, nor did exotic objects such as supermassive black holes.

The researchers are now recreating this initial state on a supercomputer and performing an evolutionary calculation forward in time based on the known laws of physics. If the theories about the Big Bang and the dark components of the cosmos are correct, these simulations should actually produce galaxies that appear exactly as we observe them.

While the principle of this approach is straightforward, it is difficult to implement in practice. This is because the physical laws to be calculated include not only gravity, magnetohydrodynamics and radiation transport, but also processes of star formation and stellar evolution, as well as the growth of supermassive black holes and their energy input at the centre of galaxies. All in all, this results in a so-called multi-scale and multi-physics problem of enormous complexity which is processed by means of specially developed simulation programmes.

Here is an example: using the AREPO code, it was possible to develop a special method using an unstructured grid that moves with the flow to simulate the hydrodynamics of cosmic gases. This allows automatic local adjustment and a high level of geometric flexibility in the resolution achieved, making it ideal for tracking galaxy formation on the computer.

Nonetheless, it makes enormous demands in terms of the computing power required to simulate a representative section of the universe. Fortunately, modern supercomputers are getting better at delivering this kind of performance, often thanks to several hundred thousand interconnected cores. Using these in such a way that they all work together simultaneously on a closely interlinked system such as the evolution of the universe is an extremely challenging algorithmic problem. This is because the computing operations performed on the huge amounts of data have to be distributed in such a way that individual computing cores do not have to wait for each other. If this is successful, cosmological simulations can be accelerated enormously by exploiting this parallelised approach.

Modern hydrodynamic simulations of cosmic evolution: each illustration shows the same section from a simulation of the IllustrisTNG project, except that different physical information is visualised in each case, ranging from dark matter and the stellar distribution to the X-ray luminosity of the ionised hot gas between the galaxies.

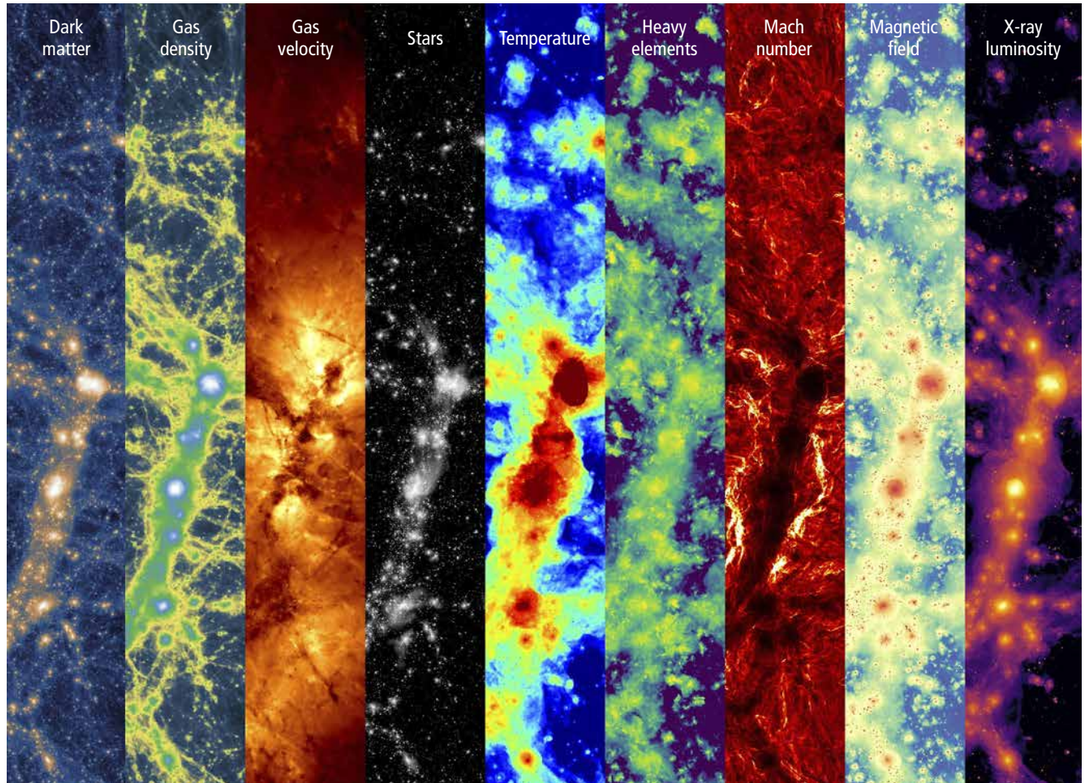


Illustration: IllustrisTNG Collaboration

Illustration: Wiki Commons/Federal Ministry of Finance

Special stamp issued by Deutsche Post in recognition of the Illustris project.

For example, the elaborate simulations of galaxy formation created by the IllustrisTNG project typically took about 20 million processor hours: with a single fast computing core, this would have taken well over 2,200 years. As a parallel simulation on a supercomputer with about 16,000 cores, the team was able to complete the operation in less than two months. For information: the IllustrisTNG project is one of the world's largest and most comprehensive astrophysical simulation series, carried out by a team of internationally collaborating researchers since 2011.

The results obtained have proved to be a real treasure trove in terms of the theoretical understanding of galaxy formation. Interestingly enough, the calculations produce galaxies of different shapes whose morphology and size are very similar to those observed. The distribution of galaxies in space also exhibits a pattern whose statistical properties corresponds very well to the observed galaxy distribution. This is even true if one divides the galaxies into finer groups, such as only blue galaxies (those that actively form stars) and red galaxies (those with hardly any young stars/none at all).

Particularly fascinating predictions concern the role of supermassive black holes at the centre of galaxies. As galaxies grow, these gravity traps devour enormous amounts of gas. In large galaxies, they grow to masses beyond 1 billion solar masses. In particularly active phases, huge amounts of energy are released, causing some objects to be quasars that shine brighter than the combined light of all the host galaxy's stars. It has long been suspected that the black holes can act on galaxies in this way, potentially having a key influence on their evolution.

IllustrisTNG calculates this link too, albeit based on highly simplified assumptions. This enabled us to confirm that the influence of black holes on the evolution of large galaxies is particularly significant: they ensure that further star formation is suppressed at some point, starting in the centre and then spreading to the outer regions. In this way, they act as a kind of limiter on the maximum size that galaxies can reach, also ensuring that the characteristic red colour of the large elliptical galaxies is preserved. If the physics of black holes is left out of simulation calculations, this inevitably leads to the creation of galaxies with far too large a stellar mass – and they are also blue. Such systems do not exist in the universe.

The situation is similar with dark matter: if one simply omits it in the simulations or assigns it completely different properties from those theoretically assumed, then either no galaxies are formed at all or only galaxies with properties that deviate strongly from the galaxies that can be observed in our universe. Simulation calculations are thus capable of testing the validity of cosmological and astrophysical theories. At present, everything seems to suggest that dark matter and dark energy do actually exist.

Illustration: MPA Garching

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www.mpa-garching.mpg.de/galaxyformation

Kathrin Dörfler, Harald Kloft and Dirk Lowke

The Challenge of the Large Scale

Additive manufacturing in construction: 3D printing technologies are to be used to explore materials, processes and structural design in new ways. The aim is to create buildings in an individualised, cost-saving and resource-saving manner.

Unusual design with a sustainable orientation and an approach to coastal protection construction based on additive manufacturing. The FLOWall project received the Iconic Award 2022 in the category CONCEPT – Visionary Architecture.

Illustration: Robin Dörfler & Harald Kloft / TU Braunschweig

You don't have to be an architect or urban planner to be able to predict that the demand for building structures such as houses, apartment complexes and towers will continue to increase worldwide in the coming decades, as will the need for infrastructure projects such as roads and noise barriers, sewage treatment plants, schools and hospitals. The reasons for this are dynamic urbanisation, a steadily growing world population and pent-up demand on the part of China and the emerging countries, not to mention the need to establish more energy-saving forms of construction in view of the energy transition and a more climate-friendly approach to building in view of climate change.

So the global challenge facing construction is to produce more buildings with less resources and lower levels of emissions. However, the construction industry is not currently prepared to meet these challenges economically or ecologically, whether in terms of technology or personnel. The reasons for this lie in the specifics of the construction processes and the prevailing construction techniques. Building is bound to a particular location: labour, construction machinery and industrially produced semi-finished products (i.e. prefabricated raw material, workpieces or semi-finished products) have to be brought to the construction site, and a structure has to be produced under the given conditions. This fundamentally distinguishes construction processes from industrial manufacturing processes in stationary production facilities. As such, on-site production in the construction industry always requires individualised planning and production, which is why the processes of industrial series production cannot be applied on a one-to-one basis.

In addition to their structural function, buildings embedded in cities and landscapes always have to be integrated in their surroundings in terms of design and sociocultural context – this is the task of architecture and urban planning. The complex interplay between these factors means that technological innovations have difficulty finding their way into the construction industry. This is why today's construction processes are still dominated by traditional craft construction techniques such as the shuttering,

Automation saves time. Shotcrete 3D printing developed at TU Braunschweig is a robot-controlled, additive manufacturing process in which the concrete is accelerated by the controlled addition of compressed air before it exits the nozzle.

Illustration: Janna Vollrath/TU Braunschweig

Foto: Robin Dörrie/TU Braunschweig

The challenge of the large scale: reinforced concrete components are digitally produced in a combined process of shotcrete 3D printing and precise surface finishing by means of CNC milling.

reinforcement and concreting of structural components in reinforced concrete construction, and the individualised fitting and joining of industrially produced semi-finished products in timber and steel construction.

Traditional building techniques also make it difficult to use innovative materials such as ultra-high-strength concretes or carbon concretes: instead simple, mass-intensive construction methods and component shapes are favoured that can be produced using conventional building materials and are inefficiently utilised. As a result, the demand for resources in the construction industry continues to rise. Additive manufacturing, or AM for short, is a novel technology from industrial manufacturing that has the potential to become a key digital technology for a resource-efficient construction industry. The manufacturing processes of additive manufacturing differ fundamentally in their characteristics from craft construction techniques because components are produced solely through the digitally controlled application of material, usually in layers, without preceding formwork or subsequent forming processes.

The use of AM in construction enables the achievement of two previously incompatible objectives, namely automation and individualisation. Another advantage of additive manufacturing methods is that material is only assembled where it is structurally or functionally required. This is a key advantage over traditional construction techniques such as concreting, where the space between the formwork elements is filled completely with material. Using additively produced, high-definition and shape-optimised concrete components, it is possible to reduce mass by as much as 50 percent. In addition, AM opens up entirely new possibilities in terms of structural design, especially with regard to shape optimisation and functional integration.

This is the starting point of the DFG Collaborative Research Centre/Transregio "Additive Manufacturing in Construction (AMC) – The Challenge of Large Scale", established at TU Braunschweig and TU Munich at the beginning of 2020. TRR 277 is carrying out fundamental research into the new AMC technologies from the perspective of the construction industry. An integrative research approach is being pursued where structural design, material behaviour and manufac-

Illustration: Lidia Atanasova / TU Munich

Other potential applications for mobile robot research platforms are conceivable in connection with additive manufacturing processes.

turing processes are viewed and researched as inseparable entities. Accordingly, the individual projects are interdisciplinary in nature, involving researchers in the fields of architecture, civil engineering and mechanical engineering.

The transfer of additive manufacturing to large scale construction ultimately combines ecology and economy and has the potential to fundamentally change the way we build in the future. In the central priority area of TRR 277, various material-process combinations are being investigated with a particular focus on the interaction between process and material. The second focus is on research questions arising from this that are systematically supported by material and process modelling. Finally, the third focus area is dedicated to the interfaces between additive manufacturing processes and the process of design and construction.

In the first funding period, the materials traditionally used in construction, i.e. concrete, steel and wood, are the subject of research from the perspective of additive manufacturing. Concrete in particular is predestined for the free-form design enabled by AMC. This is because additive manufacturing of concrete (the term 3D concrete printing is also frequently used) does away with the formwork process normally required for concreting. On the other hand, there is a challenge here: the material hardens during the printing process and reaches its so-called long-term strength at an early stage.

In additive manufacturing with concrete, there are two distinguishable technologies for the layer-by-layer construction of concrete components: firstly, so-called depositing processes in which the concrete matrix of coarse aggregate (CA), cement (C) and water (W) is mixed in advance and then deposited by layers in strands, and secondly "selectively binding particle-bed processes", in which a layer of dry particles (CA or CA + C) is first applied and then selectively bound by means of a phase of cement paste (C + W) or water (W) which has flow capability.

The most common method for 3D printing concrete is currently layer-by-layer deposition using extrusion. Experts understand this to mean that the plastically deformable fresh concrete is continuously pressed out of a shaping opening under pressure. With a conventionally concreted component, the fresh concrete is compacted after being placed in the formwork in order to achieve the properties in the hardened state, but this work step is not provided for in additive manufacturing. The bond between the layers is created by gravity, predominantly via chemical bonding.

An alternative is "shotcrete 3D printing" (SC3DP) developed at TU Braunschweig. This is a robot-controlled, depositing additive manufacturing process in which the concrete is accelerated by the controlled addition of compressed air prior to nozzle discharge. In contrast to gravity-induced depositing, the build-up of a component during extrusion takes place with additional kinetic energy. This compacts the concrete and at the same time creates a sound mechanical bond between two successive layers. The control of deformation behaviour, called rheology, and of setting behaviour is achieved in the SC3DP process by adding concrete additives to the fresh concrete stream.

In future, the consortium will look into the interplay between material, process and structural design, not least subject to the more rigorous requirements of resource-efficient and low-CO_2 manufacturing processes. Accordingly, the focus of the mission statement for the proposal of the second funding phase has been refined from "The Challenge of Large Scale" to "The Opportunities for High Impact" with regard to environmentally sound construction. On the materials side, low-CO_2 concretes and earth-based materials such as clay are to be investigated from the point of view of additive manufacturing. But there will also be a focus on new sustainable approaches for the structural design and joining of additively manufactured components.

Illustration: Alexander Straßer / TU Munich

Infinity node made of concrete, produced by means of particle-bed 3D printing.

Additive Manufacturing in Construction has the potential to produce digital manufacturing technologies that are tailored to the individual needs of the construction industry. Combined with the spatial freedom of mobile robotics, this has the potential to provide considerable freedom in terms of individual shaping. In addition to possible applications in building construction, AMC can also offer completely new approaches in terms of individualised infrastructure construction. In coastal protection, for example, shape-optimised structures are conceivable where it is not the solidity of the components that resists the impacting forces but the capacity to largely absorb these forces through shape and material structure. This approach is currently being researched in TRR 277 in cooperation with the Junior Research Group "Future Urban Coastlines" at TU Braunschweig, which also aims to integrate renaturation into structurally efficient coastal protection structures.

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https://amc-trr277.de

Ursula Prutsch and Clemens van Loyen

Gateway to the Future?

Urban transformations: slavery and colonialism once shaped Porto Maravilha in Rio de Janeiro – since 2011, a public-private partnership project has been in progress to bring about a comprehensive transformation to the notorious waterfront. Scholars in the field of American studies assess the aspirations and realities of social participation, multiculturalism and ethnic equality.

Porto Maravilha with the futuristic building of the Museum of Tomorrow and the new tram on Maua Square; Rio-Niterói Bridge can be seen in the background.

Illustration: Shutterstock

In the port district of Rio de Janeiro, known as Porto Maravilha ("marvellous port"): "Finally we have a First World means of transport" – this is how one passenger describes the eye-catching, French-designed tram that went into service here five years ago, linking Rio's financial district to Porto Maravilha. The ugly city highway dating back to the era of the military dictatorship was torn down as well as part of a modernisation project: it had literally overrun the impoverished neighbourhood.

To replace it, new streets were laid out in the notorious port district encompassing several neighbourhoods: greenery was added to pavements, underpasses were constructed to divert traffic from pedestrian squares, and façades were renovated. What is more: a local art museum and a "Museum of Tomorrow" were created along with other attractions for visitors, including a boulevard that passed along the old docks. This now leads to tourist highlights such as the world's largest mural – "Etnias" by graffiti artist Eduardo Kobra – as well as Latin America's biggest aquarium and highest Ferris wheel. This "revitalisation project" followed a global pattern of port transformation that had previously been tried and tested elsewhere: even the planning team was flown in especially from abroad.

So it is not surprising that the large-scale urban project Porto Maravilha has become the largest public-private partnership scheme in Brazil's history to date. Officially approved in June 2009, it attracted both national and international attention in the wake of the 2014 World Cup and the 2016 Summer Olympics in Rio de Janeiro.

But first, back to the beginnings: the political decision-makers believed that a fundamentally transformed Porto Maravilha would become a permanent place of residence and a centre of experience for various social classes and ethnic groups. In this way, it would reflect multicultural Brazil and, precisely because of this diversity, attract international investors, as well as creating jobs. The expectation was that the "revitalised" elements would replace the reality and images of a neglected and even dangerous port district with a permanently improved image of a safe and open living environment. Several billion

When urban identity seeks to display its past: the Porto Maravilha historical museum.

Illustration: Clemens van Loyen

Illustration: Clemens van Loyen

A popular attraction that tourists love to photograph: the mural "Etnias" by graffiti artist Eduardo Kobra.

dollars have been invested to date in infrastructure, museums and façades, with funding being provided by the city of Rio, the state of the same name and the federal government (through the Lula da Silva and Dilma Rousseff governments) as well as private investors.

Under the title "Door into the Future?", a DFG project has conducted research into the "debates surrounding the transformation of Porto Maravilha". Project participants asked whether and how civil society groups were involved in this transformation process or whether decisions were made on a top-down basis only. The main interest here was whether the vision of social, ethnic inclusion was realised – perhaps only in rudimentary form – or whether this notion was more a question of façade and rhetoric. With this research programme, the project formed part of the international research group "Urban Ethics. Conflicts about the good and proper conduct of life in 20th and 21st century cities".

One key insight to have emerged is that manifest ethical conflicts arose wherever poorer groups were resettled and dispossessed because they stood in the way of the desired vision of condensed space for new middle classes. For example, descendants of former slaves found themselves in a real estate dispute with the Franciscan Order: the latter was seeking to remove the residents' right of abode so as to be able to rent out the properties at better rates, even receiving legal support from Germany in the process. It was not until the parties concerned had drawn up counter-assessments on ownership structures with the support of academic experts that the planned expropriation was stopped. In this way, the studies also showed how effective inner-city and transnational collaboration can be when it is embedded in a global network.

The construction of the Museum of Tomorrow was also the subject of much debate, given its ethical and universal aspirations set in the heart of a port district shaped by historical conflict. While seeking to symbolise modernity, the Museum of Tomorrow stands on a site that is historically particularly fraught because it is closely linked to the centuries-long history of slavery in Brazil. For this reason, local Afro-

Brazilian movements consider the institution to be out of place.

Since the city's oldest slum, Providência, is also located in the immediate vicinity, the plan was to enable residents of the favela to visit the museum free of charge. But in order to do this, they have to go through an involved process of registering and providing proof of their place of residence. In many cases, locals did not even know where the registration office was located. And due to the high admission fees – for comparison, the Berlin counterpart of the Museum of Tomorrow offers free admission – the facility is once again a place of social privilege, despite the fact that the transformation of the port district was propagated based on a vision of social inclusion. As is characteristic of any former slave society, poverty is very much linked to dark skin colour and shaped by the still deep-seated belief that there is a "natural ethnic order".

Flooded with light and constructed in modernist style: view of the spectacular entrance hall of the Museum of Tomorrow, a facility that attracted considerable public controversy.

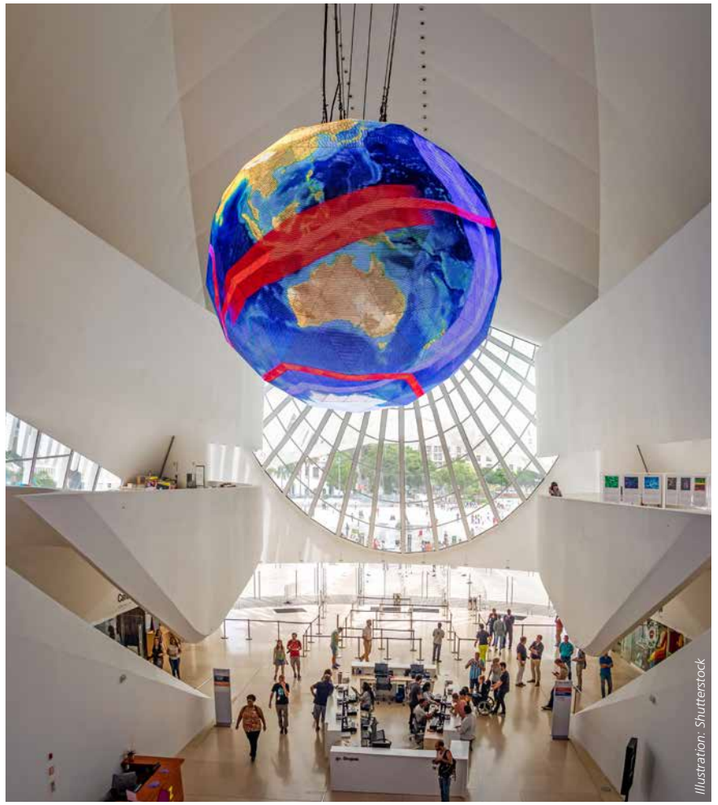

Illustration: Shutterstock

The researchers also focused on Valongo Wharf: having been a UNESCO World Heritage Site since 2017 because more than one million African slaves once landed there, the aim was for it to be regarded as a place of remembrance of injustice. For years now, a struggle has been going on to establish a slavery museum and a documentation centre at the wharf. Both have so far failed due to individual interests and Rio's evangelical mayor, Marcelo Crivella (2017–2020), who has since been voted out of office and who disrespected Afro-Brazilian cultures, leaving Valongo Wharf to become derelict. One factor that contributed to the dismal state that prevails in large parts of Porto Maravilha was the financial bankruptcy of the state of Rio in the wake of the major sporting events and the coronavirus pandemic. But another reason the plan to turn the port district into a globally attractive investment area failed was because the bay on which it is located is virtually dead in ecological terms – something that can be both seen and smelt.

Just a stone's throw from the wharf is the favela Providência: while this has become the site of regular clashes between military police and drug gangs, it is also a place of social creativity and civic engagement. Individual Porto Maravilha projects also included the installation of an expensive cable car running up the rather low hill Morro da Providência. Residents opposed its construction without success. The cable car was only used for two months and has now been in a state of disrepair for five years. But the cable car station building now serves as a popular community restaurant, providing a view of the entire harbour area and also attracting non-favelados to the hill.

Based on participant observation at events as well as conversations with project leaders, residents, activists and cultural workers, it has become apparent that while inclusion is a worthy goal, it is yet to be realised in many cases. Social participation in Brazil is traditionally linked to the struggle for citizenship and the right to healthcare, education, housing, mobility and clean drinking water – regardless of religious or ethnic affiliation. Yet it is precisely these rights, first enshrined in the 1988 Brazilian Constitution, that Porto Maravilha has failed to respect. It was found that "inclusion" has largely been a buzzword used by the city administration and has hardly resulted in any improvements at all. The population was not involved in concrete decision-making processes, nor were the voices of the people heard when it came to forced evictions from unused buildings.

Illustration: Clemens van Loyen

The newly built cable car, which was considered a prestige project, has been in disrepair for a long time, though the station building with its view of the harbour remains a popular attraction.

The example of the cable car demonstrates that well-intentioned improvements to the infrastructure were rejected because they were perceived as a rather disrespectful interference in a living environment that was already held in low esteem. For black activists in particular, hopes have been dashed that the "lead culture" of a "racial democracy" formulated in 1933 to prescribe a conflict-free multiethnic life in Brazil would finally be called into question. Multiculturalism is an image projected through the large-scale graffiti, but behind it lurk the longstanding inequalities and conflicts that underlie people's mindset and behaviour.

The fact that there is an interest in the historical heritage of this place and that there is a living culture of remembrance that goes beyond the archaeological sites is exemplified by the historical walks that are offered, an activity that is in considerable demand among both domestic and foreign tourists. But only a sound culture of debate can result in a wise, compromising approach to this heritage, with its memorials such as the "slave cemetery" (a mass grave). This must include a willingness to accept historical facts, even if they are detrimental to the desired glamour of a global urban showcase.

It must be possible to negotiate with actors at different levels. The transformation of Porto Maravilha is not complete. At least it can be said that this is the first urban transformation project that has ever included the Afro-Brazilian population and their cultures of memory, albeit only in symbolic form in many cases. The research also indicates that while millions of dollars were spent with good intentions, little consideration was given to residents' socio-economic conditions and needs. Through their analyses, the participants of the research project hope to contribute to advancing the debate on a more socially and ethnically just transformation in this historically important port district.

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The Deutsche Forschungsgemeinschaft

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The DFG places special emphasis on early career support, gender equality and scientific relations with other countries. It also funds and initiates measures to develop and expand scientific library services, data centres and the use of major instrumentation in research. Another of the DFG's core tasks is to advise parliaments and public interest institutions on scientific matters. Together with the German Council of Science and Humanities, the DFG is also responsible for implementing the Excellence Strategy to promote top-level research at German universities.

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It was like a reunion between good friends and companions who had missed each other's company for a long time. On two occasions, science, politics, media and society had to miss out on their cherished first get-together of the New Year due to the coronavirus pandemic: this time around, in 2023, it was finally possible to hold the DFG's traditional New Year's reception once again. More than 400 guests gathered in the Leibniz Hall of the Berlin-Brandenburg Academy of Sciences and Humanities in mid-January to wish each other all the best as they got together to assess what these eventful times had brought forth and what lay in store in the future. Federal Research Minister Bettina Stark-Watzinger was present, as were several members of the Bundestag and representatives of the federal states, the heads of the major research organisations and numerous universities, as well as a number of members of the diplomatic corps. Numerous members of the DFG statutory bodies also came to Berlin to attend the event, with former President Ernst-Ludwig Winnacker receiving a particularly warm welcome. "The Role of Science and the Humanities in Tackling Crises" was the theme of President Katja Becker's New Year's speech: it was followed by lots of conversations at the buffet, in the hall and in the side corridors, bringing the evening to a late conclusion.