Excellence Strategy of the Federal and State Governments

Universities of Excellence Funding Line

TUM. THE ENTREPRENEURIAL UNIVERSITY.

Innovation by Talents, Excellence, and Responsibility

Technical University of Munich

Commencement of funding 1 November 2019

Overall Strategy

for Funding in the Excellence Strategy of the Federal and State Governments

TUM. THE ENTREPRENEURIAL UNIVERSITY.

Innovation by Talents, Excellence, and Responsibility

Technical University of Munich

Munich, 6 December 2018

Place, date

Wolfgang A. Herrmann, President

Brief profile of the university

Established in: 1868

28 **Academic structural units: a)** 15 **Departments:** Aerospace & Geodesy (under formation) | Architecture | Chemistry | Civil, Geo and Environmental Engineering | Management | Education | Electrical and Computer Engineering | Informatics | Mathematics | Mechanical Engineering | Medicine | Nutrition, Land Use, and Environment (Weihenstephan) | Physics | Political Sciences/Governance | Sport and Health Sciences – **b)** 6 **Integrative Research Centers:** TUM Institute for Advanced Study | Munich Center for Technology in Society | Munich School of Engineering | Munich School of BioEngineering | Campus Straubing for Biotechnology and Sustainability | Munich School of Robotics and Machine Intelligence – **c)** 7 **Corporate Research Centers:** Center for Functional Protein Assemblies | TUM Catalysis Research Center | Research Neutron Source Heinz Maier-Leibnitz (FRM II) | TranslaTUM: Translational Research in Oncology | Walter Schottky Institute for Semiconductor Physics – Center for Nanotechnology and Nanomaterials | Hans Eisenmann Forum – World Agricultural Systems Center | Institute for Food and Health

177 **Study programs:** 45 Bachelor | 109 Master | 12 State Exam | 11 other

4 **Clusters of Excellence:** EXC 2089 e-conversion | EXC 2094 ORIGINS: From the Origin of the Universe to the First Building Blocks of Life | EXC 2111 Munich Center for Quantum Science and Technology (MCQST) | EXC 2145 Munich Cluster for Systems Neurology (SyNergy)

22 **Profile-forming areas: a) Research:** Astro- and Particle Physics | Quantum Science & Engineering • Physics of Condensed Matter | Structural Biology • BioEngineering | Artificial Machine Intelligence and Robotics | Catalysis | Sustainable Mobility • Intelligent Traffic and Transport Systems | Tumor Research | Neurosciences | Immunology – **b) Teaching:** Teach@TUM – Teacher Education | Entrepreneurship Education | Interdisciplinary BSc Study Programs • International MSc Study Programs – **c) Transfer:** TUM*entrepreneurship* • IP Competence | Interactive Secondary School Network | Science & Technology Communication – **d) Further areas of activity:** TUM Graduate School | TUM Global PostDoc | TUM Faculty Tenure Track | August Wilhelm Scheer Visiting Professorship Program | International Center • International Representations | TUM.Asia Singapore | TUM Science & Study Center Raitenhaslach

A. Text of proposal

A.1. Summary

As a result of two decades of tempestuous reform and growth, the Technical University of Munich (TUM) is committed to an overall medium- and long-term strategy aimed at advancing the university from a renowned position into the international top league. Inspired by its entrepreneurial spirit and encouraged by its proven potential for continuous renewal, TUM now ventures to undertake the most profound transformation in its 150-year history.

TUM AGENDA 2030 responds to rapid societal change in the *age of digitalization and biologization*, which poses unprecedented challenges for science and technology. To this end, TUM is fundamentally reforming "German Engineering" in conjunction with the **humanities and social sciences** towards a **"Human-Centered Engineering"** to excel its interdisciplinarity and widen its intercultural horizon in research and teaching (*Responsible Innovation*). For this strategy, TUM draws its vigor from the excellence of its foundational disciplinary profile. However, it reinforces its brand-defining, transformative collaborative research by realigning its system of subjects in a **governance structure** based on a matrix-interwoven **system of schools**. Overall performance efficiency benefits from a digitalized and internationalized **university administration.**

TUM's central mission aims to enable the diverse **talents** for scientific careers, new entrepreneurial ventures, and future labor markets. Building on the success of the TUM Institute for Advanced Study with its spill-over effects on the entire university community, the interdisciplinary approach to thinking and action finds new expression in the institutes of **Data Science, Technology Design**, and **Life Long Learning.** Motivated by the performance-oriented Recruitment and Career System (Faculty Tenure Track), TUM once again highlights its persistence in renewing both content and structure: comprehensive **gender and diversity** policy | talent-promoting **career development** across all levels, for the first time focusing on the mid-level academic staff (CareerDesign@TUM) | **advanced entrepreneurship** strategy with international scope of action. Supported by targeted science communication and international university marketing, **global alliances** with emphasis on Europe and Africa extend TUM's vital science and industry network.

With this overall strategy, TUM is opening up new international horizons for its academic talent, stimulating competitive advantages that make this university a leading reference for science, business, politics, and society.

A.2. Status quo and prior achievements

Building on its higher education policy reform concept to expand autonomy and capacity for action (1998)[1], TUM was able to demonstrate its capability for renewal in the two program phases of the Excellence Initiatives 2006–2018. The central idea of scientific excellence that must constantly prove itself through competition has been internalized by the university community in a lasting way. **Interdisciplinarity** and **internationality** characterize the profile of TUM. Its **entrepreneurial spirit** means constant readiness for change and risk. The content-related and structural emphases of the institutional strategy TUM. THE ENTREPRENEURIAL UNIVERSITY. show directly measurable results (Table 1, Fig. 1). These suggest that TUM, based on its reform-proven reference, now has the potential to advance into the international top league if the excellence strategy is implemented consistently (A.3).

Table 1: TUM key data before ExIni I and during ExIni II

	5-year period before ExIni I[a)]	5-year period ExIni II[b)]	Effect ExIni I+II
Scientific Publications			
– Web of Science	12,078	28,615	+137 %
– ESI/Web of Knowledge	10,359	20,887	+102 %
– Scopus	13,118	33,644	+156 %
Citations			
– ESI/Web of Knowledge	66,023	186,990	+183 %
– Average (per paper)	6.4	9.0	+41 %
TUM Junior Fellows[c)] (without ERC)	23	36	+56 %
ERC Grants		62	
Faculty Appointments	153	164	+7 %
– from abroad	33	64	+94 %
– *female* professors	13	45	+246 %
– TT-professors		81	
External offers to TUM professors	27	50	+85 %
– of which fended off	56 %	79 %	
PhDs completed	3,346	5,108	+53 %
Alumni Network/Members	(2005) 26,696	(2017) 81,099	+204 %
Third-party research funds (M €), total	(2005) 147.4	(2017) 336.3	+128 %
– w'out Excellence Initiative	147.4	304.9	+107 %
– of which DFG-CRCs/TRRs	14.7	26.6	+81 %
– of which EU programs	8.9	32.1	+261 %
Fundraising (M €)	39.4	88.3	+124 %
– of which TUM Univ. Foundation (M €)		46.4	
Construction volume (M €)	404.7	598.3	+48 %
Spin-offs founded	96	313	+226 %

| a) **2001–2005**. – b) **2013–2017**. – c) **TUM Junior Fellows:** Independent Research Group Leaders of the following programs: Bayerisches Netzwerk für Klimaforschung (bayklif) • BioSysNet Independent Research Groups • BMBF Independent Research Groups • Emmy Noether • Elitenetzwerk Bayern • Heisenberg • Helmholtz • TUM-IAS Carl von Linde Junior Fellows (until 2016) • Liebig Fellowships • Max Eder • Sofja Kovalevskaja • Zentrum Digitalisierung Bayern.

| 1 Adopted by the Bavarian State Parliament (2006/2009) into the amended Higher Education Act.

A.2.1. Overall profile and starting situation

A.2.1.1. Self-image

Living up to its role as a *servant of society* (mission statement), TUM is committed to the progress of innovation in areas of science that promise to sustainably improve people's lives and their coexistence. This is the basis for interdisciplinary research programs focusing on: *Health & Nutrition* • *Energy & Natural Resources* • *Environment & Climate* • *Information & Communication* • *Mobility & Infrastructure*. TUM constantly measures itself against international benchmarks (particularly Stanford, Imperial College); it lives internationality as a connection between the homeland and the world and focuses on educating talents with a sense of values, on promoting entrepreneurial thinking and action, on dialogue with politics, business, society, and on embodying a living generational contract (value chain school – university – professional life). TUM also uses the life experience of its *alumni* and *Emeriti of Excellence*, who are actively involved in the agenda of the university, as a factor in its development policy, as it likewise values its *donors* and *patrons*. The TUM family uses a distinctive culture of appreciation as the most important source of sustained value creation.

A.2.1.2. Quantitative growth

For around 15 years, TUM has had to shoulder tempestuous *quantitative growth*, the burden of which mainly affects teaching and administration (Fig. 1). Despite the early introduction of selection procedures (so-called aptitude test, since 1999), *the number of students has doubled*. Personnel development was not able to keep up with this trend adequately, despite *a far more than doubled third-party funding*, substantial state investment, and foundation successes. Through innovative reform measures (including appointment policy and structural measures), a remarkable *qualitative performance improvement* was nevertheless achieved during the entire growth phase, cf. Table 1 and the statements that follow.

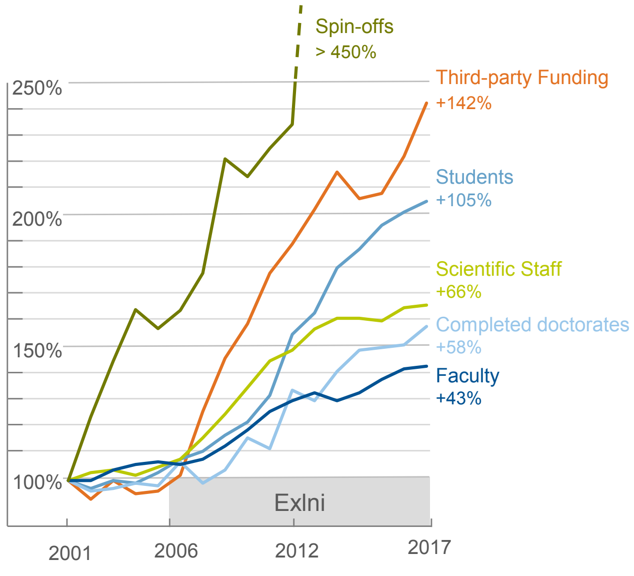

Fig. 1: Development of TUM key data 2001–2017 (based on 2001 ≙ 100 %)

A.2.1.3. Qualitative growth – Milestones

Inspired by the Excellence Initiative, the innovation dynamism manifests itself in an exemplary way in more recent milestones:

Appointment policy. TUM FACULTY TENURE TRACK (TT), as the core element of the new TUM Faculty Recruitment and Career System[2] (ExIni II), is highly successful. This model, as a "genuine tenure track" (*up or out* principle), has unfolded its pilot function in the German higher education system. Not only is the **TUM^{100} Strategy** ahead of schedule in 2018, but the main features formulated at the time have also proven to be fully effective. Of the **100 new recruits** to TT professorships (W2): **50 % come from abroad**, from excellent addresses (MIT, Harvard, Oxford, Cambridge, ETH), so that "brain gain" expectations are also met • **36 %** are **foreign citizens** • **38 %** are **female professors**, predominantly with families (effective dual-career policy) • **52 %** are **younger than 35** • all took up their positions after an **appointment process that lasted only 7 months** on average • the **success rate for applications** was about **2 %**, in the linked program **MaxPlanck@TUM < 1 %** • **15 %** have so far received **calls to chairs** (full professorships) at universities in Germany and abroad. A new challenge was how to handle W2 professors (so-called extraordinarius professors), previously appointed for life, in cases of demonstrably outstanding records of achievement. Since here a *promotion* according to the TT model is prohibited by law, TUM has opened up the option for appointment as full professor if certain excellence criteria are fulfilled (so-called "lighthouse appointments" without public advertising but employing an international peer review system)[3], see p. 27. Here too, concordance with the strict, differentiated requirement profiles of the TUM Faculty Recruitment and Career System[2] has been established.

Beyond the TUM^{100} Strategy, **40 TT professorships** have been approved through the competitive federal-and-state program (BMBF, 2017). This not only reinforces profile areas and strengthens fields with high potential (p. 17ff.), but also fertilizes areas that have previously stood in the shadows due to untapped cooperation potential, such as above all the new School of Humanities, Social Sciences & Education (p. 44), prevention research in the Sport and Health Sciences/Medicine (p. 32, Ref. 37), the Agrosciences (p. 32, Ref. 38), or the TUM Institute for Technology Design (p. 49). In this way, TUM wants to make areas that have traditionally had a lower priority much more dynamic in the future. – Likewise, **TUM FACULTY EXECUTIVE SEARCH**[4] has proven to be a shining

| 2 **TUM Faculty Recruitment and Career System** from July 1,2012 (Statute according to Bavarian university law). – **Principles for Evaluations in the TUM Faculty Recruitment and Career System** (2013).

| 3 **Guiding criteria:** Speakership DFG Collaborative Research Center, Excellence Cluster, FET Flagship, etc. • High-level competitive research program (e. g., ERC Advanced Grant) • High-ranking science prize (e. g., Leibniz Prize, AvH/Max Planck Research Award, German Future Prize etc.) • Offer from a leading university / research institution • Contributions towards profile development of TUM.

| 4 Hired for TUM via so-called **"lighthouse appointments,"** among others: Prof. Francis Kéré as an international star architect for sustainable building (cf. TUM.Africa Concept, p. 51) • the leading material and catalysis chemist Prof. Roland A. Fischer (currently VP of DFG), p. 19 • engineer Prof. Sami Haddadin (German Future Award, 2017) as director of the newly founded MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE, p. 18 • sociologist Prof. Sabine Maasen as director of the MUNICH CENTER FOR TECHNOLOGY IN SOCIETY, p. 20, 45.

example of recruitment policy for highly successful top talents (headhunting). The 2017 target for **internationalization of the faculty** (20 %) has nearly been reached.[5]

New departments. TUM School of Education (2009) • TUM School of Governance (2016) / Bavarian School of Public Policy[6] • Department of Sport and Health Sciences (restructured 2012) • Department of Aerospace and Geodesy (under foundation 2018).

Education policy / teacher training. Student research center Berchtesgaden • senior class courses with secondary schools in Gauting and Garching • TUM Applied Technology Forum (2012, forerunner of BayWiss 2016) • Deutsches Museum Munich: institutional interconnections (research, teaching, public outreach), teacher-student laboratory TUM*Lab* • Ernst Otto Fischer Seminar Burghausen (advanced training for teachers in chemistry) • training center AuTUM for commercial occupations (*apprenticeship training*, currently 146 apprentices) • Teach@TUM (BMBF – Quality Campaign Teacher Training, 11 M €), cf. C.3.1/2.

Teaching program, promotion of young talent. TUM:*Junge Akademie* to boost top students (2010) • TUM:*Agenda Lehre* in the Quality Pact for Teaching (Joint Science Conf., 29.6 M€; Internationalization 2.0, 1.9 M €) • integrated campus management for the entire "student life cycle," including digital application infrastructure (2010) • Academic and Student Affairs Office (2010): comprehensive, participative bundling of all processes in study and teaching (Teaching Board, Teaching Assembly), institutionalized quality management; university-wide systems accreditation (2014) • international elite courses of study to promote excellence (currently 11 programs, including TopMath MSc/PhD program) • TUM Teaching Constitution (2018), cf. Appendix C.3.1/2.

Teaching and research structures. ***TUM Graduate School*** (2009). **– *Integrative Research Centers:*** TUM Institute for Advanced Study (2006) • MUNICH CENTER FOR TECHNOLOGY IN SOCIETY (2012) • MUNICH SCHOOL OF ENGINEERING (2009) • MUNICH SCHOOL OF BIOENGINEERING (2015) • MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE (2017) • TUM Campus Straubing for Biotechnology and Sustainability (2017) • TUM Campus Heilbronn for Economic Sciences (2018) • Ecosystems Research Station Berchtesgaden (2018). **– *Research centers:*** TUM Catalysis Research Center (2008) • Energy-efficient and Sustainable Design and Building (2010) • ZIEL – Institute for Food and Health (2002, restructured 2014) • Leonhard Obermeyer Center for Digital Construction (2013) • Hans Eisenmann Forum for Agricultural Sciences (2008, restructured 2018) • TUM Research Center for Functional Protein Assemblies (2017) • Bavarian NMR Center (2001) • TranslaTUM

| [5] **Since 2013**: 64 of the professors were recruited from abroad (out of 164, corresponding to 39 %), 40 of whom are German "returnees."

| [6] Founded 1950; New Constitution Act of the Bavarian State Parliament (2014): assignment to TUM.

(2017). **– *Transfer center:*** Professionalized project assistance for research/technology transfer TUM ForTe (2009). **– *TUM Science & Study Center Raitenhaslach*** (2016). **– *Large-scale research:*** Research Neutron Source FRM-II Garching: institutional government support / Research Center Jülich (Helmholtz); annual budget ca. 45 M€.

Entrepreneurship. TUM International GmbH – THE UNIVERSITY COMPANY (2007) • TUM*entrepreneurship* in the national EXIST IV competition "Founder Culture" (BMWi 2011/2014; 3.2 M€) • International Venture Programs in USA (Silicon Valley) and Europe (Eindhoven, Copenhagen, Lausanne) • Currently > 70 spin-offs p. a. (2017), cf. p. 23f./37.

International alliances. European Universites Alliance EuroTech (TUM, DTU Copenhagen, TU Eindhoven, EPF Lausanne, Technion Haifa, École Polytechnique Paris; 2007/2018) • German-French Academy for the Industry of the Future (Inst. Mines Télécom – TUM, 2015) • TUMCREATE Singapore – Campus for Research Excellence and Technological Enterprise (TUM-NTU, 2010): 114MSGD funding NRF Singapore 2010 – 2021 • Imperial College London (2018) • Skolkovo Institute of Science and Technology, Moscow (2018).

IT strategy. Leitmotif "Digital University" and CIO/IO board (2002) • IT service center (2010) • TUM Online (2010) • TUM:*Agenda* IT (2012) • central registration for IT security (2013) • MOOCs (Coursera/edX, 2013)[7] • cross-departmental university-wide WAP application (2014; 1.1 M€) • founding member ORCID Consortium (2016) • Taskforce Digitalization (2017) • TUM Data Protection Rules and Regulations (2018).

University library. Certified ISO 9001 (2007), DIN ISO 9001:2015 (2016) • publishing house **TUM.University Press** (2017) • Advisory Center for Research Data Management (2016) • TUM Open Access Publication Fund (2013, DFG-supported)[8].

Fundraising. TUM University Foundation (2010; entry into endowment fundraising, currently > 60 M€ basic capital) • firmly established acquisition structure.

A.2.1.4. Infrastructure Development

The development of the **research infrastructure** at TUM may be unprecedented nationwide, thanks to straightforward structural policy and the sustained, reliable science and technology policy of the Free State of Bavaria, supported by competitive federal funds for new research-oriented construction projects of supraregional significance (Article 91b Federal Constitution): In the 15-year period since 2003, a total of **> 1,7 B€** has been invested in research-oriented and departmental new construction and renovations (107 M€ of which is federal funding); **979 M€** since 2012 (period of ExIni II), Table 2. For the coming years, Bavaria has committed itself, among other projects, to

| [7] > 350,000 registrations; MOOCS4MASTERS program for potential international MSc students.

| [8] TUM is among the leading supporters of Open Access in Germany; in 2017, no other university in Germany funded more Open Access articles.

new buildings for the Department of Electrical and Computer Engineering (510 M€) and the Department of Aerospace, Aeronautics, and Geodesy (30 professors plus infrastructure), Table 2, with a further investment of **674 M€** (without ongoing renovations). State funding has also been obtained for new research infrastructure, including the MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE (26 M€ infrastructure/staff plus 2,200 square meters of state property). TUM plays a prominent role in the digitalization strategy of the Free State of Bavaria, which is anchored in the budget and highly endowed (Bavarian Center for Digitalization – headed by M. Broy, TUM).

Table 2: Construction measures since the beginning of ExIni II (2012)

Garching Campus (251 M€). Renovation/expansion for Chemistry, Physics • TUM Center for Energy and Information (MSE) • TUM Research Center for Functional Protein Assemblies[a)] • TUM Entrepreneurship Center • Bavarian NMR Center (for 1.2 GHz NMR)[a)] • StudiTUM (workplaces for students, 1,325 sq. m.) • auditorium buildings (2) • New Mensa Building • Campus Center GALILEO (PPP model). – **Munich Campus (265 M€).** New construction for Dept. Sport and Health Sciences • renovations (incl. historic clock tower) • StudiTUM (630 sq. m.) • Vorhoelzer Forum student cafe. – **Weihenstephan Campus (69 M€).** StudiTUM (1,300 sq. m.) • Hans Eisenmann Center for Agricultural Sciences. • International Beverage Research Center. –**Straubing Campus (62 M€).** Laboratory buildings (2) • renovations. – **Heilbronn Campus (Dieter Schwarz Foundation).** Teaching/research high-rise, 3,040 sq. m. (2018/19). – **University hospital (311 M€).** TranslaTUM: Translational Cancer Center[a)] (67 M€) • Surgery Center (52 M€) • renovations. – **Rentals Munich/Garching: ca. 11 M€ p. a.** (including MCTS, Informatics/Mathematics). – **TUM Science & Study Center Raitenhaslach: 10 M€.**
Decided/approved new construction measures (from 2018): 674 M€. Total relocation of Dept. of Electrical and Computer Engineering to Garching: 510 M€ • Livestock Husbandry Weihenstephan: 63 M€ • Leibniz Center for Food Systems Biology: 40 M€ • Munich Center for Quantum Engineering: 37 M€ (2019)[a)] • StudiTUM Medicine: 7 M€ • Multiple Sclerosis Research Center: 42 M€ (of which Tschira Foundation 25 M€).

| a) 50 % federal participation in research construction, Article 91b German Federal Constitution.

The **annual state budget for TUM** has increased 72 %, from 289 M€ (2006, beginning of ExIni I) to currently **498 M€** (excl. hospital); the **community of professors** in the same period (2006–2018) grew from 407 to **548 members (+ 35 %)**. In the "Increasing Student Numbers" federal-and-state pact (since 2008), TUM has received **771 new personnel positions** due to outstanding performance data, 537 of which are permanent.

A.2.1.5. Regional, national, and international networking

From its small beginnings as a polytechnical school in 1868, TUM has evolved from generation to generation into an internationally respected university of distinction. It has long been anchored ***regionally*** in multiple locations, with the campus sites in Munich, Garching, Freising-Weihenstephan, and Straubing as well as other teaching- and research-specific locations in southern Bavaria. – The institutional extension to the ***national environment*** is beginning in Heilbronn (Baden-Württemberg) where, with the help of the *largest foundation project in the history of German universities*, a permanently fully financed economic science campus with 20 professorships is being set up (> 1 billion €, Dieter Schwarz Foundation). – TUM's first ***international presence*** was opened up in 2002 in Singapore, where TUM Asia Pte. Ltd. and its subsidiary TUMCREATE (2010) have a record of success in teaching and research (currently > 80 doctoral candidates). Liaison offices in Brussels (EuroTech Universities Alliance), Beijing, Mumbai, São Paulo, San Francisco, and Cairo act as anchors in regions of the world that had previously not been fully tapped. Now TUM alumni clubs[9] are active or being established there. The advanced international presence and visibility of TUM are conducive to students studying abroad[10] and to winning students from abroad (currently 30 %), and to recruiting qualified young talents (postdocs, TT professors), cf. Table 1.

In accordance with its mission statement, TUM does not restrict its definition of performance to the prevalent **international university rankings** (p. 13), which do not inquire about the practical impact of graduates on regional business enterprises, schools, or health care institutions. The performance dimension of an education that is occupational yet immersed in science is something TUM has had in its genes ever since it was founded. As a logical consequence – especially in light of an "entrepreneurial spirit" increasingly put into practice by academic youth – the concept of the **"entrepreneurial university"** was developed[11] and enforced with comprehensive measures to promote entrepreneurial thinking and action (TUM*entrepreneurship),* Table 6 (p. 24).

The **regional strategy network** of TUM, which has yielded success in manifold ways will be comprehensively utilized and systematically expanded:

■ **Ludwig-Maximilians-Universität Munich (LMU).** It has long been the strongest research partner (*from 2019*: 24 joint CRCs/TRRs, 4 Clusters of Excellence)[12]. TUM's overall strategy now relies on long-term, institutionalized joint centers: ***Recent examples (2018)*** emerged from the Bavarian BRAIN CAMPUS initiative on artificial intelligence: **MUNICH CENTER FOR HUMAN DEVELOPMENT OF DIGITAL SYSTEMS** (TUM/LMU) combines complementary strengths to investigate the interaction of humans and digital systems (e. g., media informatics/psychology LMU; visual computing/ergonomics TUM) and thus fertilizes the overall strategy. The center will be equipped with 3+3 new professorships.

| 9 The international **alumni network TUM*net*** currently comprises > 81,000 members, Table 1.

| 10 Study visits abroad > 3 months: 30 % of students. – Architecture students spend a full year of the 8-semester BSc study abroad (around 40 contract faculties).

| 11 **Institutional Strategies I/II** of the Excellence Initiative since 2006. – **First TUM spin-off:** Carl von Linde (1879), today's Linde AG. – **TUM*entrepreneurship*:** Companies founded by members of TUM since 1998 (> 800) currently provide > 15,000 jobs. Currently ca. 70 spin-offs per year (2017). To date, 8 TUM spin-offs listed on the stock markets, e. g., Celonis AG (founded 2011) > 1 billion USD shareholder value ("Unicorn").

| 12 **Agreement on the Top-Position Advancement of the Munich Universities**, Aug. 1, 2005 (TUM • LMU • Bavarian Ministry of Science and the Arts). – See also: **ONE MUNICH Strategy Forum** (A.3.2.3.2, p. 47).

• **BAVARIAN RESEARCH INSTITUTE FOR DIGITAL TRANSFORMATION (BIDT):** It brings together several Bavarian universities under the umbrella of the BAdW (headed by A. Pretschner, TUM)[13a] into a holistic research approach that comprises all the technical, social, economic, and legal aspects of digitalization, with a focus on educating young talents; annual budget 7.5 M€. • **MUNICH CENTER FOR MACHINE LEARNING (MCML)**: The BMBF-financed initiative (LMU/TUM; speaker: Th. Seidl, LMU)[13b] gains advantageous feedback, mainly from the AI/robotics research and the extensive industry network of TUM.

■ **Fraunhofer Gesellschaft (FhG):** On-campus partner with new building complex in Garching: SECURITY IN INFORMATICS (AISEC; headed by C. Eckert/G. Sigl, TUM) • FOUNDRY, COMPOSITE, AND PROCESSING TECHNOLOGY (IGCV**;** headed by W. Volk, G. Reinhardt, K. Drechsler, TUM) • COGNITIVE SYSTEMS research center (FhG/TUM, under construction, joint appointment "Engineering of Resilient Cognitive Systems").

■ **Max Planck Society (MPG):** Joint appointment pilot program **MaxPlanck@TUM** for TT professors (10 so far), p. 4. • Significant participation in numerous top-level collaborative research projects (currently 16; e.g., EXCs/CRCs) • **MPG School "Matter to Life":** integrated international MSc/PhD Excellence Program MPG, TUM, U Heidelberg, U Göttingen (since 2018).

■ **Helmholtz Center Munich** (HMGU; headed by M. Tschöp, TUM). 24 of 52 institute directors are TUM professors (18 of which are joint appointments). From this the Munich **BioEngineering Alliance** (p. 18) and the **Munich School for Data Science @ Helmholtz**, **TUM & LMU** (headed by F. Theis, TUM/HMGU) as a thematic, strategy-supportive Graduate School have developed (2018, cf. A.3.2.3.5).

■ **fortiss GmbH** (founded 2009)[14] – Research institute of the Free State of Bavaria for software-intensive systems and services. Application platform of TUM for the strategic research field "Artificial Intelligence" (cf. LMU, FhG, and p. 18).

■ **German Aerospace Center (DLR).** As one of the world's leading research centers of its kind, DLR in Oberpfaffenhofen near Munich (> 1,700 employees) is the strongest strategic partner of the new TUM Aerospace and Geodesy Department (high potential research area, p. 20f. and Ref. 31).

■ **Munich Aerospace** (founded 2010) is a teaching and research alliance of TUM, DLR, UBwM, and Bauhaus Luftfahrt with participation of the relevant industries (e. g., Siemens, Airbus Industries).

| 13 Further TUM participation: a) Lisa Herzog (Political Philosophy and Theory). b) D. Cremers, F. Theis, S. Günnemann.

| 14 **TUM-affiliated institute** (headed by: H. Krcmar, TUM). Currently > 120 employees, 37 cooperation projects with industry. Shareholders: Free State of Bavaria 67 %, FhG 33 %. – *Topical fields*: Software & Systems Engineering, Cyber-Physical Systems, Information Systems, Digital Innovations, Broadband Infrastructure and Network Policy, E-Government.

■ **Munich University of Philosophy (HPM).** With the humanities profile of HPM (theology, philosophical anthropology, ethics), the strategic partnership Technology – Philosophy enriches the new socio-cultural claim of TUM in education and research (p. 41ff.), especially in the profile forming research area "Artificial Intelligence" (p. 18).

■ **University of Television and Film Munich (HFF).** Joint film/television productions supporting the TUM outreach policy to strengthen public awareness of the STEM subjects, with a special focus on women in technical professions (web series "Technically Single," 2018). Cooperation with TUM:*Junge Akademie*, jointly with the

■ **University of Music and Performing Arts Munich (HMTM),** an alliance partner that is likewise in the immediate vicinity of TUM, inspiring its cultural life.

■ **Deutsches Museum Munich** (General Director: W. Heckl, TUM). The most prominent public outreach partner, with permanent TUM presence (TUM*Lab*, science communication); annually >> 1 million visitors, above all from younger generations.

■ **European Patent Office Munich. German Patent and Trademark Office Munich.** Strategic partner in the "patent capital Munich" in increasing IP awareness and professionalizing patent, trademark, and license policy.

A.2.1.6. Networking with science and business

The significance of the **cooperation partners** – universities (particularly LMU Munich, p. 8f.), Max Planck/Helmholtz/Leibniz/Fraunhofer, and industry – is of paramount strategic importance for TUM, not least as documented in numerous research associations (DFG-CRCs/TRRs, Clusters, German Health Centers[15], Knowledge & Innovation Communities / EIT). For example, 51 "bridge professorships" are occupied jointly with non-university research, 31 of which are in executive positions at HMGU, DLR Oberpfaffenhofen (HHG), the Leibniz Institute for Food Systems Biology, and the Deutsches Museum Munich. Several MPG directors are among the 212 honorary professors of TUM. The inter-institutional cooperation is therefore reliably based on people, thus constantly revealing new joint research fields (including EXCs).

As an "entrepreneurial university," TUM has an extensive cooperation network with industry and business associations, and not only in the first-class high-tech location of Munich, as documented for example by the **"TUM Partners of Excellence"** (26)[16] with special ties to "their university" (TUM University Foundation, among others). TUM's educational performance is conducive to the success of numerous alumni in leading

| [15] TUM participates in all six **German Health Centers**: Neurodegenerative Diseases • Diabetes • Translational Cancer Research • Cardiovascular Research • Infectious Diseases • Lung Research.

| [16] **TUM Partners of Excellence:** Airbus • Altana • Audi • Bayerischer Bauindustrieverband • BMW • Bosch • Clariant • Dräxlmaier • Evonik Industries • FC Bayern München • Google • Herrenknecht • Infineon • Linde • MAN • Nestlé • Rohde & Schwarz • RWE • SGL Carbon • Siemens • Süd-Chemie • Trumpf • TÜV-Süd • Vereinigung der Bayerischen Wirtschaft • Volkswagen • Wacker Chemie – 6 DAX30, 3 MDAX, 1 SDAX.

corporate positions (at Clariant, Linde, BMW, Infineon, Nestlé, and Rohde&Schwarz, among others) or successful owner-managed companies. The TUM-IAS building was a gift of the BMW Group (10 M€), cf. A.3.2.3.4.

A.2.1.7. International Positioning

In spite of the different cultural environment but based on correspondingly broad subject portfolios (including medicine), TUM measures itself against *Imperial College London* (Europe) and *Stanford University* (USA), which are – with smaller numbers of students – clearly superior in their overall research performance. While TUM holds its own in ranking results (A.2.2.1) in comparison with any national and most European competitors, the profile forming research areas (A.2.2.1.1) come up to the benchmarks mentioned above, increasingly supported by a series of top-level appointments, including from internationally leading universities. The overall strategy (A.3) is now instrumental in catching up with the international elite class, utilizing substantial experience from successfully implemented measures and exploiting the opportunities originating from **international alliances**:

■ **Imperial College London (ICL).** In all of Europe, ICL has the portfolio of subjects and policy orientation most comparable to TUM's and is thus the perfect strategic **"Flagship Partner"** (2018). – *Agreed* are: joint faculty appointments • research cooperations, especially in artificial intelligence, digital medicine, bioengineering, aerospace engineering, engineering design (ICL Dyson School) • exchange of scientists and administrative staff (A.3.2.5.3). – *Target 2020:* TUM "White City Campus" branch of ICL to further internationalize TUM*entrepreneurship* (A.3.2.1.6); *target 2026:* **TUM.London**, p. 50.

■ **EuroTech – European Universities Alliance**[17]**.** This teaching and research network combines complementary strengths, uses the *Design Academy Eindhoven* in building up TUM Technology Design (A.3.2.3.6, p. 49), and prepares itself for EU support as an alliance of Europe's leading technical universities (Call 2018, "European Universities").

■ **German-French Institute for the Industry of the Future.** Bi-national research alliance TUM – Inst. Mines Télécom (IMT) founded in 2015 for AI research addressing industrial problems in the context of Industry 4.0 (joint financing 2.0 M€ p. a.), p. 21.

■ **Nanyang Technological University Singapore (NTU).** Strategic partnership in the CREATE program of the Singapore NSF (TUM/NTU research focus areas: electromobility, intelligent autonomous transportation systems), cf. p. 19.

■ **Stanford Institute of Design.** Benchmark partnership for the TUM Institute for Technology Design (A.3.2.3.6, p. 49).

| [17] TUM – DTU Copenhagen – TU Eindhoven – EPFL – Technion, Haifa – École Polytechnique, Paris.

■ **Singapore University of Technology and Design** (**SUTD**, founded 2009, associated with MIT). Flanking partnership in building up TUM Technology Design (A.3.2.3.6, p. 49).

■ **Skolkovo Institute of Science and Technology** (**Skoltech**, founded 2011). Up-and-coming university in Moscow, that measures itself according to international best standards in the research fields: Life Science & Biomedicine • Engineering & Advanced Materials • Energy Efficiency • Quantum Technology. The strategic partnership (2017) builds on the complete thematic concordance with TUM.

A.2.2. Analysis of strengths and weaknesses based on previous achievements and successes

"Talent is our capital, and reputation is our return." This is how TUM's most important strength can be summarized. While the strengths identified in the 2011 SWOT analysis (Ch. 2.7, p 32f., Institutional Strategy ExIni II) have been stabilized and expanded, there is ample room for overcoming the weaknesses, even if some systemic deficits have been eliminated: Today TUM commands a continuous **faculty tenure track career path** • the **inward flow of the best** foreign students and scientists has grown significantly, accelerated by customized programs • **quality management** for the study programs has been professionalized (e.g. system accreditation) • **international departmental evaluations,** as a central element of the SWOT analyses, vitalize strategic orientation planning • **intellectual property** has been given a value of its own through sensitizing measures, with well-defined principles for adequate compensation in industry cooperations as well as in the founding of technology-based start-ups. The risk that high competitive pressure imposes on personnel recruitment in the metropolitan region of Munich was counteracted in part by reputational gain, flexible compensation schemes for professors, and reliable provision of resources.

In spite of bold structural measures – the MCTS should be emphasized (A.3.2.2.4) – the **Humanities & Social Sciences** are still *subcritical*. Therefore, special attention is given to this performance domain, which is all the more important for the future, in the overall strategy (A.3). The stakeholders in the technical sciences also increasingly recognize that connections to the humanities and social sciences must be indispensably anchored in the education of future engineers and scientists (A.3.2.2.2–4). Programmatic approaches to opening horizons in curricula also facilitate the integration of the natural sciences and other fields (such as informatics, artificial intelligence, "social computing", data literacy) that are, in many cases, still insufficiently integrated into teaching and research in the engineering sciences.

TUM is daring to take on the **modernization of the administrative apparatus** (A.3.2.5.3), a subject so far hardly addressed in the German higher education system, as one of the greatest conceivable challenges (service orientation • digitalization • internationalization).

By prioritizing personnel development, accompanied by circumspect change management, this goal of the TUM AGENDA 2030 gradually appears to be achievable, with immediate spill-over effects on research excellence.

The 2011 SWOT analysis was updated and differentiated into the most important fields of action (Tables 3, 5, 6). It is the result of intertwined evaluation processes (e.g., departments), surveys (students, alumni), and an ongoing iterative dialogue process at all levels of TUM including external views (e.g., Board of Trustees, University Council, science/business partners, international peers).

A.2.2.1. Organization and quality of research

Strengthening strengths, overcoming weaknesses: This objective drives the overall strategy at all levels. To this end TUM employs the broad, differentiated spectrum of subjects in natural/engineering sciences • medicine/life sciences • economic/social sciences, with the planned strengthening of humanities and social sciences (A.3.2.2.3).

Rankings. In all international rankings, TUM holds its ground as the **leading technical university in Germany.** Nationally, TUM is in the undisputed top trio with the "full universities" in Munich (LMU) and Heidelberg[18,19], though the latter two are missing engineering. Furthermore, the outstanding position in the "Global University Employability Ranking" (#6 int./#1 Ger.)[20] shows that excellent research and education are fully in harmony at TUM. In the Artificial Intelligence Research Review, TUM plays in the global top league (#6 int./#1 Ger.: THE 2018) together with MIT (USA) and NTU (Singapore). Its leadership role as the entrepreneurial university is shown in the national *"Founding Radar"* of the Stifterverband (#1 Ger.) and the *German Startup Monitor* (#1 Ger.), see Fig. 1.

Clusters of Excellence. A targeted recruiting and profile-shaping policy resulted in interdisciplinary focus areas that were able to qualify as Clusters of Excellence, in part based on the novel TUM format of *Integrative Research Centers* and proactive measures to foster collaborative research: **ORIGINS • SyNergy • e-conversion • MCQST**. Thus with strong TUM participation (46 PIs) and by virtue of strengthened partnerships with LMU, MPG, and HMGU, the cooperative potential of 98 PIs is being used to stabilize and expand Munich's top position as a science hub.

| 18 **ARWU Shanghai Ranking 2018:** #48 int./#2 Ger. **– Reuters Most Innovative Univ. 2017:** #40 int./#1 Ger. **– QS World Univ. Rankings 2019:** #61 int./#1 Ger. **– THE World Univ. Rankings 2019:** #44 int./#2 Ger.

| 19 **ARWU Shanghai Subject Ranking 2018**: #50 int./#2 Ger. TUM Chemistry – #15 int./#1 Ger. TUM Environmental Science & Engineering – #30 int./#1 Ger. TUM Food Science & Technology.

| 20 **2018 int. top-10**: Harvard, CalTech, MIT, Cambridge, Stanford, **TUM,** Princeton, Yale, U Tokyo, NU Singapore. – LMU #26 int./#2 Ger.; Heidelberg #38 int./#3 Ger.

Table 3: Performance dimension Research: SWOT analysis

STRENGTHS
- International research excellence: chemistry • physics • medicine • electrical & information engineering • informatics (competitive with benchmarks such as Stanford, MIT, IC London)
- TUM INSTITUTE FOR ADVANCED STUDY: forum of international research excellence
- Internationally competitive career and recruiting system: TUM Faculty Tenure Track, TUM Executive Search
- Excellent scientific and economic environment in the Munich metropolitan region – in combination, a leading position Europe-wide
- Strong, stable research alliances (regional, national, international)
- Continually high level of research in engineering sciences based on professional practice and industrial challenges ("German Engineering")
- Increasingly high amounts of third-party research funds: > 336 M€/2017 (#2 Ger.), Fig. 2; #1 Ger. in EU programs: 32.1 M€/2017, of which ERC Grants account for 5.0 M€
- Constantly expanded or modernized research buildings (p. 6f., Table 2, p. 25)
- Support programs for students, doctoral candidates, postdocs, TT professors, and visiting professorships
- Professionally strong mid-level academic staff, but see A.3.2.1.2.
- Interdisciplinary competence bundling in Integrative Research Centers

WEAKNESSES
- Engineering sciences: Gaps in basic research, inadequate integration of natural/life sciences and medicine (only 2 out of 26 CRCs, no Cluster of Excellence)
- Sport and Health Sciences, Architecture: Not yet adequately established, despite outstanding individual achievements, to connecting with cutting-edge research
- Untapped transdisciplinary innovation potential due to traditional departmental structures ("silo thinking")

OPPORTUNITIES
- High development potential for the technology-related profiling of social/political sciences ("Responsible Research & Innovation"; start 2012/2016)
- Pull effects on weaker research domains, and overcoming of departmental boundaries through structural integration (e. g., TUM Technology Design, A.3.2.3.6), fostered by new governance structure (A.3.2.5)
- Stimulating *TUM Industry on Campus* concept with specialized focus areas: additive manufacturing, autonomous systems, artificial intelligence, robotics
- Strategic research alliances with leading (technical) universities: EuroTech (p. 11), Imperial College London (p. 11), NTU Singapore (p. 11)
- Administrative reform according to international best standards (A.3.2.5.3)

THREATS
- Burdensome logistics for interaction (6 locations), a historical outgrowth of campus decentralization due to renewal and expansion
- Difficulty of attracting top international researchers due to high cost of living in the Munich Metropolitan Area and state wage restrictions
- Inhibition of innovation due to high density of regulation and German "CYA" mentality

Science prizes. Successes with the A. v. Humboldt Foundation are indicators for international visibility: TUM ranks first (2017) in terms of the number of visiting scientists in the natural/engineering sciences, and third in life sciences (2017). In the highly competitive Humboldt Professorships (since 2008) – linked with the appointment of top talents from abroad – TUM is in the lead (Rost, Jacobsen, Kramer, Tschöp, Schulz, Caccamo). Since 2012, a total of 6 DFG Leibniz Prizes have been awarded to D. Cremers (IN), H. Dietz (PH), V. Ntziachristos (EI/ME), B. Wohlmuth (MA), S. Haddadin (IN/EI), B. Schulman (CH/MPG). S. Albers, M. Beneke, and H. Boche were appointed to TUM as Leibniz prizewinners. Awarded 26 times since 2010, the Maximiliansorden, the highest honor of the Free State of Bavaria for science and art, has been awarded to 10 members of the TUM faculty[21a]; 7 TUM engineers became IEEE Fellows[21b]. F. Theis (MA, Helmholtz) received the Erwin Schrödinger Prize, A. Bode (IN) the Konrad Zuse Medal, H. Spohn (MA) the Henri Poincaré Award. 16 TUM professors have been elected to high-ranking national academies (Germany, USA, Sweden) since 2010.

Bibliometric rankings. The lead TUM maintains over the other German technical universities has widened. According to ESI, 101 TUM members are currently among the top 1 % of those most cited in their fields of expertise in the 22 Essential Fields of Sciences; with an *h*-factor > 100, TUM is represented 10 times (Web of Science)[22].

Third-party research funding. The bottom line on third-party research funding[23] exceeds the expectations of ExIni 2012. The steep upward trend (cf. Fig. 2, Table 1) includes all sources of funding: public (largely DFG, BMBF, EU) – business & industry – foundations and other third-party funding providers. At a historic high of **336 M €** (2017)[23] the distribution is roughly 2/3 – 1/6 – 1/6. A particularly strong impact is due to: 109.4 M€ DFG, 26.6 M€ of which is from 32 CRCs (9 speakerships)[24] and 51.4 M€ from Research Groups, Priority Programs, and Research Training Groups (17 speakerships in all), in addition to smaller funding lines • 32.1 M€ EU (#1 Ger.), including 52 active ERC Grants und coordination of the KIC “EIT Food” • 58.9 M€ from industry (since 2013 > 6,000 contracts; since 2012 > 280 cooperative patent applications) • 53.7 M€ from foundations (excl. Heilbronn) and other third-party funding providers.

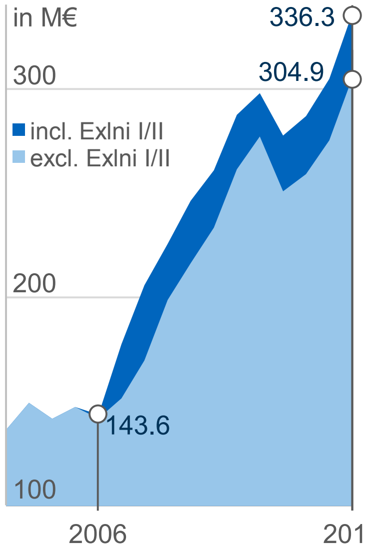

Fig. 2: Annual Income from Third-party Research Funds since 2002

Research programs of the European Research Council (ERC). Not least as a consequence of the Tenure Track program, the balance of ERC grants in all categories has improved by leaps and bounds (currently 100, #2 Ger.). The ERC Starting • Advanced

| 21 a) Milberg, Rummel, Schmidbaur, Schwaiger, Trappe, Broy, Herrmann, Schmitt-Landsiedel, Hirzinger, Kögel-Knabner. – b) Kramer, Lugli, Boche, Gräb, Buss, Steinbach, Cheng.

| 22 Herrmann, Schwaiger, F. Hofmann, Friess, Wagner, Schunkert, Kessler, R. Huber, Schömig, Cirac.

| 23 **Current DFG Funding Atlas 2014–2016:** TUM #4 DFG Funding • #1 EU-Horizon 2020 • #4 Federal Funding • #5 AvH Funding by individuals (#2 Engineering Sciences • #1 Natural Sciences) • #2 Industrial Collective Research (IGF/AiF). – **Total third-party research funds:** TUM #2 Ger. (after RWTH Aachen).

| 24 **From 2019**: 33 CRCs/TRRs, of which 10 TUM speakerships.

• Consolidator • Synergy • Proof of Concept Grants are distributed 45 • 22 • 24 • 1 • 8. Proposal preparation was supported through coaching measures using funds from ExIni II (> 200 K€ p. a.).

TUM Integrative Research Centers (IRCs). The cross-departmental and interdisciplinary bundling of expertise is the prerequisite for internationally competitive top-level research in the natural, engineering, and life sciences as well as in medicine. The TUM-IRCs take this into account: Following the launch of this policy through the MUNICH SCHOOL OF ENGINEERING (2010, in the forefront of ExIni II) and the MUNICH CENTER FOR TECHNOLOGY IN SOCIETY (ExIni II, 2012), TUM has pursued it consistently: MUNICH SCHOOL OF BIOENGINEERING (2015), MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE (2017). These institutions primarily serve research and hold the right, essential to their identity, to award doctorates; but they also prepare the ground, by offering thematically linked teaching and interdisciplinary education, for newly emerging job markets. Straightforward development of this approach is the objective of the overall strategy (A.3), as well as the management of previously lower-priority areas or of fields that have been weaker in research (p. 4/32 and Ref. 37, 38).

Promotion of early-career talent. The university-wide **TUM Graduate School** had substantial impact on the structured doctoral education: 8,455 doctoral degrees since 2009, with mandatory membership of all doctoral candidates[25]. In this the **DFG Graduate Schools** (2) and the **DFG Research Training Groups** (10) contribute by promoting quality and sharpening the focus. Of the 6,380 currently registered doctoral candidates, around 400 are being advised by TT professors appointed since 2013. As **TUM University Foundation Fellows**, the best international doctoral graduates (*as of 2018:* 100; 50 % female; < 3 % success rate of applications) can start their independent scientific careers as postdocs at TUM, their new home for research, cf. A.3.2.1.3.

Understanding of quality, cf. A.2.2.3. The relevant quality criteria and benchmarking (including departmental evaluations) apply to the diverse yet interdependent performance dimensions research • teaching • promotion of young talent • transfer/entrepreneurship. The *TUM Research Code of Conduct* (2013) and the *Guidelines for Safeguarding Good Scientific Practice and Dealing with Scientific Misconduct* (2015) set binding standards for integrity and compliance. The commitment to diversity and equality of opportunity is regulated in the *TUM Diversity Code of Conduct* (2012), the requirement for integrity in the *TUM Fundraising Code of Conduct* (2011), and the principles for employment of relatives, spouses, and life partners in the *TUM Dual Career Code of Conduct* (2016). In the future,

| [25] **International Graduate School of Science and Engineering (IGSSE), ExIni I:** 219 PhD theses completed since 2007 (138 “Tandem projects”, 12 departments); at present 202 ongoing PhD theses.

an independent vice president will assume responsibility for all compliance issues (A.3.3, Ref. 83, p. 59; see also C.7.1).

Performance Indicators. Continuous monitoring of academic performance is guidelined by the common international indicators, taking cultural-and-subject-specific requirements into account (*Target Agreement System*); beyond that, among others, engagement in the academic community is being considered (Appendix C.2.8; 10 criteria), see also A.2.2.3 (p. 25f.). Guiding excellence indicators are repeatedly referred to, e. g., Ref. 3, p. 4.

Research and business cooperations have been codified in a separate set of rules with the standing of statutes (2013) to achieve orderly bilateral relations and – for the first time in Germany – adequate remuneration for intellectual property (15 % contractual premium, "intangible asset" income to date > 7.5 M€). The mandatory 20 %-overhead is used predominantly for structural development and excellence measures (e. g., TUM-IAS, promotion of young talent, gender/diversity programs, infrastructural measures).

Fundraising. A consistent fundraising policy has inspired the engagement of patrons in a way that is not typical of conditions in Germany, thanks to the reputational gain (ExIni I/II): currently > 60 M€ endowment capital (TUM University Foundation, founded 2010), plus 95 M€ for teaching/research programs since 2012 (266 M€ since 1998). TUM is thus the *leading Fundraising University in Germany*.

A.2.2.1.1. Profile-forming research areas with a leading international position

Based on their long-standing research performance, *Physics* • *Chemistry* • *Informatics* • *Electrical and Computer Engineering* • *Medicine* rank among the internationally leading departments (Table 4).

Table 4: TUM's strongest departments in research

Physics: 7 CRCs/TRRs, 25 ERC Grants, 3 Leibniz Prizes. – *Top performance areas*: biophysics, nanotechnology, nuclear/particle/astrophysics, condensed matter. – *EXC:* Universe, ORIGINS, NIM, CIPS^{M}, MAP, MCQST, e-conversion. – **Chemistry**: 6 CRCs/TRRs, 8 ERC Grants, 3 Leibniz Prizes. – Catalysis, energy materials, structural biology, biochemistry, molecular biotechnology. – *EXC:* CIPS^{M}, NIM, MCQST, e-conversion. – **Informatics**: 2 CRCs/TRRs, 11 ERC Grants, 3 AvH Professorships, 7 Leibniz Prizes. – software engineering, robotics & machine learning, digital biology, computation in engineering/natural sciences, visual computing, extreme scaling. – **Electrical and Computer Engineering**: 1 TRR, 3 SPPs, 9 ERC Grants, 1 AvH Professorship, 3 Leibniz Prizes, 7 IEEE Fellows. – telecommunications, robotics, sensor technology, optoelectronics, neuroengineering, embedded & cyber-physical systems. – *EXC:* CoTeSys, MCQST. – **Medicine**: 13 CRCs/TRRs, 28 ERC Grants, 1 AvH Professorship, 1 Leibniz Prize. – Cancer, heart/circulation, diabetes, neurosciences, allergies/immunology, medical imaging. – *EXC:* CIPS^{M}, SyNergy.

Crucial to the implementation of the overall strategy and an important performance condition, however, is the development of excellence from *cross-disciplinary focus areas* to which the leading researchers from nearly all departments contribute. The *TUM*

Corporate Research Centers and *TUM Integrative Research Centers* as well as *research clusters* with excellent external partners embody this strategy institutionally. Disciplinary strengths – supported by a targeted, sustained recruitment policy – have thus been oriented toward **profile areas of internationally top-ranked research**, see also Appendix C.2.8. **B** indicates the *international*; *European* Benchmarks.

■ **Astro- and Particle physics.** Fundamental research between the largest structures in the universe and the smallest building blocks of matter, the forces between them, and the underlying symmetries. – *Key projects*: EXC Universe, ORIGINS; CRC 1258 Neutrinos and Dark Matter; International IceCube Neutrino Observatory at the South Pole. – **B:** Harvard, Princeton, Stanford; Cambridge.

■ **Physics of Condensed Matter • Quantum Science & Engineering.** Leading fundamental research on solid-state elements, nanostructures, and new functional materials (lasers, solar cells, sensors, supermagnets). – *Key projects:* EXC NIM, MCQST; CRC/TRR 80; new research building "TUM Center for Quantum Engineering" (from 2019). – **B:** Yale, Harvard; Delft, DTU Copenhagen, Vienna.

■ **Structural Biology • BioEngineering.** Fig. 8 p. 52. The most convincing example of the alliance between natural and engineering sciences and medicine: *biomedical imaging & microscopy • synthetic biology • biomolecular systems • biomaterials • biomedical technologies & computing • bioinformatics.* With top-level appointments, high-ranking science awards, outstanding infrastructure (e. g., Munich Compact Light Source, MuCLS), and prominent research alliances[26], this research domain finds its cross-departmental character embodied in the MUNICH SCHOOL OF BIOENGINEERING (2015; head: F. Pfeiffer). Munich BioEngineering Alliance with HMGU. – EXC CIPS[M] (ExIni I/II). – **B:** Johns Hopkins, MIT, Stanford; ETH Zurich, Imperial College London.

■ **Artificial Machine Intelligence and Robotics.** Fig. 8 p. 52. The MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE (2017; head: S. Haddadin) uses the international reputation of TUM in AI research (#6 int./#1 Ger.: THE Review 2018), combining AI with robotics and perception to shape innovative, sustainable technological solutions for health, labor, and mobility (8 departments, ca. 30 professorships/research groups). Associated as an application platform is **fortiss GmbH** (p. 9)[14]. – *Partners:* DLR, LMU, FhG, Leifheit Foundation (geriatronics). – *Industry partners:* SAP, Intel, Siemens, Infineon, BMW, Airbus, Continental. – **B:** Stanford, MIT, Tokyo, NTU Singapore.

| [26] **Leibniz Prizes:** Pfeiffer, Ntziachristos, Dietz, Cremers. – **AvH Professorships**: Rost, Tschöp. – **Top-level Professorships**: Sattler, Buchner, Sieber, Bausch, Theis. – **Collaborative Research**: 10 CRCs/TRRs (with 4 speakerships); 1 RTG, 1 ITN. – **New research buildings**: TranslaTUM, Functional Protein Assemblies, Bavarian NMR Center (with 1,2 GHz NMR). – **Strategic Partners**: HMGU, p. 9. – TUM will join the prospective HELMHOLTZ PIONEER CAMPUS, which is aiming for 20 independent research groups, partly set up with TT professorships in joint appointments (Helmholtz@TUM).

■ **Catalysis.** Fig. 8 p. 52. On a path pioneered by the organometallic research of Ernst Otto Fischer (Nobel Prize 1973), novel catalysis concepts are being investigated theoretically and experimentally in the TUM CATALYSIS RESEARCH CENTER (head: R. Fischer), for which the interdisciplinary fusion of the core domains of chemistry and physics with the engineering sciences (process technologies) guarantees its international top-level competitiveness[27]. – *Key projects*: EXC NIM and e-conversion, IRTG 2020, SPP 1928, BMBF Kopernicus, SolTech Project Bavaria. – **B:** Stanford, Harvard; MPI Fritz Haber Berlin, Leibniz Institute for Catalysis Rostock.

■ **Sustainable Mobility • Intelligent Traffic and Transport Systems.** Internationally anchored joint engineering research (8 departments). – *Focus areas:* electromobility; TUM Living Lab Connected Mobility Munich/Singapore; fully electric vehicle concepts ACar, MUTE, EVA; cutting-edge transport systems for megacities (TUMCREATE Singapore, 114MSGD 2010–2021); Hyperloop technology. – *Under construction:* Munich Mobility Alliance@TUM: competence alliance with engineering/natural sciences, informatics, city/space planning, economic/social sciences, industry (BMW, Audi, IAV, MAN, Siemens, TÜV-Süd). – *Overall strategy*: Sustainable Mobility and Autonomous Technical Systems (TUM Integrative Research Center, forthcoming). – *Key appointment*: C. Osorio (MIT), 2018. – **B:** MIT; ETH Zurich, Imperial College London, UC London, TU Eindhoven.

■ **Tumor Research.** Through a rigorous recruitment, infrastructure, and alliance policy (incl. new research building for TranslaTUM; German Consortium for Translational Cancer Research DKTK) TUM has achieved a leading position in basic and therapeutic cancer research[28]. – *Overall strategy:* cell biology of tumor-associated genes, analysis/microenvironment of tumors, new small/large animal models, molecular/ multimodal imaging for diagnostics and observation of disease progress, phase I/II clinical studies. – *Key projects*: CRCs 824, 1321, 1335; CRC/TRR 36; FOR 2033. – **B:** Memorial Sloan Kettering Cancer Center NY, MD Anderson U Texas Houston.

■ **Neurosciences.** Internationally highest level of research in cooperation with LMU, HMGU, and German Center for Neurodegenerative Diseases (DZNE)[29]. – *Key projects*: EXC SyNergy, RTG 1373, new research building (from 2019) and BMBF Competence Network “Multiple Sclerosis”; German-French Network for Epigenetics of Parkinson's; joint

| 27 **Research Partnerships**: Wacker Chemie AG (Wacker Institute for Silicon Chemistry, 9.1 M€ 2006–2021) • Clariant AG (Munich Catalysis Alliance, 6.1 M€ 2013–2021) • MPI for Chemical Energy Conversion Mülheim/Ruhr (R. Schlögl, EXC e-conversion).

| 28 **“Top Oncological Center” Award** by the German Cancer Aid Association for the “Comprehensive Cancer Center Munich”, 2014.

| 29 **Fundamental and translational research:** Genetic risk factors and biomarkers (movement disorders, neurodegeneration, multiple sclerosis, Alzheimer’s disease), neurons/glioma/immune interactions, In-vitro In-vivo-imaging/modelling, competence center NeuroEngineering (Neuroelectronics, Brain/Machine- and Brain/Computer-Interfaces). – New building for Research Center for Multiple Sclerosis (from 2019, 25 M€ Tschira Foundation + 17 M€ TUM/University Hospital/State Government).

Neuroengineering Research Alliance with Georgetown University/USA (2018), Elite Graduate Programs: Biomedical Neurosciences, Neuroengineering. – **B:** Harvard, Stanford; UC London, ETH Zurich, U Zurich.

■ **Immunology.** Combined basic and translational research expertise in medicine, life sciences, natural sciences, and engineering (particularly informatics and electrical engineering) at TUM, the German Center for Translational Cancer Research, and the German Center for Infection Research[15]. – *Focus areas*: personalized diagnosis and therapy methods for patients with cancer, chronic infections, metabolic, neurological, and cardiovascular diseases, allergies, and autoimmune diseases • integration of bio- and nanotechnologies and artificial intelligence (p. 18). – *Key projects*: CRC 1335, CRC 1321, CRC 824, CRC 914, CRC 1054, CRC/TRR 36, TRR 179, SPP 1656, RTG 1482, EXC SyNergy. Appendix C.2.8. – **B:** Harvard, MIT; Oxford.

A.2.2.1.2. High potential research areas

■ **Technology-oriented Social Sciences.** The MUNICH CENTER FOR TECHNOLOGY IN SOCIETY (MCTS; ExIni II, 2012) has opened new horizons in the social and human sciences for TUM, the "forge of technical innovators." As a cross-sectional institution firmly anchored in the university, set in motion by K. Mainzer (philosophy of science and technology) and built up by S. Maasen (sociology of science), MCTS has become the largest center for science & technology studies (STS) in the German-speaking world and is one of the three largest in Europe[30]. A.3.2.2.4, Appendix C.2.8. – **B:** Ref. 30.

■ **Computational Science & Engineering across Scales.** Bundling of the research expertise in modelling and simulation of coupled systems on different scales, numerical experiments, digital twins, and high-performance computing, which is currently available in several different departments (mainly engineering, informatics, mathematics, natural sciences). Leonhard Obermeyer Center for Digital Methods for the Built Environment, Bavarian Graduate School of Computational Engineering (with FAU Erlangen-Nuremberg), MUNICH SCHOOL OF BIOENGINEERING; *upcoming*: TUM Institute for Data Science. – Appendix C.2.8. – *Key projects:* TRR 40, SPP 1648. – **B:** U Texas Austin, Stanford, MIT, GeorgiaTech; ETH Zurich, EPFL, TU Eindhoven, DTU Copenhagen.

■ **Aerospace • Aeronautics • Geodesy.** The new department (founded 2018)[31] seizes the opportunity, in conjunction with the internationally outstanding German Aerospace

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| [30] Currently 81 staff members (of which 63 sci. staff), 5 professors, 36 ongoing PhD theses. Third-party funding since 2014: > 9,5 M € (u.a. EU H2020, DFG, BMBF, Elite network Bavaria, F. Schiedel Foundation). – **International Benchmark Universities:** *Currently*: TU Eindhoven, U Twente, CSI Mines ParisTech), TIK Oslo, STS Vienna; *Aspirational:* Cornell U, Arizona State, Virginia Tech, MIT.

| [31] Medium-term as Department Aerospace & Geodesy part of the School of Engineering, p. 52. – 30 new professorships (2019–2026). – **DLR**: > 1.700 employees at the site in Oberpfaffenhofen (Munich Area) (total > 8.000 at 14 sites), biggest experimental aircraft fleet in Europe (No. 2 after NASA).

Center (DLR, Helmholtz), to develop core competences that were previously divided among several institutions into a new profile area of "German Engineering" at TUM. With this expansion, the department will have 56 professorships (around 50 % of all university-based aeronautics and aerospace research in Germany). Appendix C.2.8. – **B:** GeorgiaTech, Purdue, Beihang University Peking; Imperial College London.

■ **Industry 4.0 • Additive Manufacturing.** A revolution with enormous potential for value creation in manufacturing and logistics – which will put its stamp on the age of "Industry 4.0" – can be expected to arise from innovative materials and new process variables for high-precision, reproducible, layer-by-layer ("additive") construction of functional and geometrically complex materials and cyber-physical systems. A strategy development originating in Mechanical Engineering is flowing, with the integration of competences from 8 departments, into a comprehensive strategy supported by the Garching Industry-on-Campus alliance **"Additive Manufacturing Campus Bavaria,"** which is currently under development (GE, Oerlikon, Linde, Siemens, Airbus). – *Key appointment*: Prof. M. Caccamo (AvH Professorship, Cyber-physical Systems in Production Engineering, 2017). Appendix C.2.8. – **B:** PennState; Sheffield, Nottingham.

■ **Nanofunctional Energy Systems.** Based upon the achievements in semiconductor/nanophysics (Schottky Institute; EXC NIM, since 2006) and flanked by the research in catalysis and energy (SolTech Project; EXC: e-conversion, 2019), a research center is being created at TUM for nanofunctional energy systems merging the natural and engineering sciences. Appendix C.2.8. – **B:** Stanford; DTU Copenhagen.

■ **Energy Efficiency and Infrastructure.** With the MUNICH SCHOOL OF ENGINEERING (MSE, ExIni II), the bundling of energy research was initiated and successfully implemented, as were cross-departmental engineering study programs. International networking took place through the International Center for Energy Research (ICER, with TUMCREATE Singapore) and the German-French Academy for the Industry of the Future (TUM-IMT; emphasis on AI/digital technologies; currently 11 TUM PIs). The research is focused on electromobility • alternative energy systems • energy materials • power plant technologies • energy-efficient and sustainable design and building. 9 TUM departments involved. Appendix C.2.8. – **B:** University of Texas Austin; EPFL, ICL.

■ **Digital Medicine • Personalized Prevention.** Through the cooperation of the MUNICH SCHOOL OF BIOENGINEERING (2017), the TUM Research Center for Protein Assemblies (2015), TranslaTUM (2017), the MUNICH SCHOOL OF ROBOTICS AND MACHINE INTELLIGENCE (2018), the Bavarian Center for Biomolecular Mass Spectrometry, and the Munich Sequencing Alliance, TUM is profiling itself with an interdisciplinary research program on prevention and precision medicine, in the fields of Machine Intelligence in Medicine (surgical assistance systems, neuroprostheses, "digital twin" of the human, nanorobots for drug transport), Genomic Medicine (Big Data, genomics, -omics technologies), and Nutrition. The network is strengthened through strategic cooperation with the HelmholtzZentrum München/HELMHOLTZ PIONEER CAMPUS and joint TT professorships to achieve an international level of performance. – *Key projects:* CRC 824, BMBF DIFUTURE "Data Integration for Future Medicine" (Spokesperson K. A. Kuhn, ME), AI Competence Network Bavaria (from 2019), Digi Med, 1000 Genome, Digi Seq. Appendix C.2.8. – **B:** Vanderbilt, Harvard; Imperial College London.

■ **Bioeconomy.** The *Integrative Research Center* TUM Straubing Campus for Biotechnology and Sustainability (head: V. Sieber) bundles interdisciplinary fundamental research and technological developments on Renewable Resources & Biogenic Materials • Side-stream Utilization & Renewable Energies • Industrial Biotechnology & Bioeconomics to accelerate the paradigm shift concerning the sustainability of chemical material conversion, while taking into account the related economic effects. Appendix C.2.8. – *Planned expansion* from 17 to 30 professorships, from 5 to 10 BSc/MSc degree programs; campus expansion: lab building for "Sustainable Chemistry" (8,000 sq.m.). – First comprehensive 5year BSc/MSc on Bioeconomy in Germany (2018) – **B:** U Queensland; DTU Copenhagen, U Wageningen, ETH Zurich.

A.2.2.2. Structure and quality of other performance areas

a) Teaching

For its **achievements in educating students**, TUM consistently receives "best" ratings from both alumni and employers[20,32]. However, the SWOT analysis (Table 5) refers to opportunities that may overcome obvious weaknesses typical of the German university system in general.

The educational goals in the TUM mission statement are professional competence "on the pulse of science" ("Abenteuer Forschung": the adventure of research), the power of judgment, and awareness of responsibility. Confident mastery of the subject and attunement to entrepreneurship should be reflected in cultural sensitivity, a cosmopolitan outlook, and social competence. The **TUM Teaching Constitution** (2018) defines the framework, flanked by binding goals, for the process of developing competence profiles and teaching formats, as well as for the students/teachers (WR 2017). Still underdeveloped in research-related study courses is the horizon of humanities and social sciences which, however, is warranted for the professional capability of tomorrow[33]. The

| 32 According to a representative survey of MSc graduates in the years 2015–2017, 90 % would choose to study at TUM again; 72 % currently have a gross annual income of > 40,000€, 87 % are interested in continuing education offers from their department; 80 % of graduates who earned their degree after 2016 rate their first job as "appropriate" for their master's qualification. Employer feedback is correspondingly positive, see "Global Univ. Employability Ranking 2018": #6int/#2EU/#1 Ger. (Ref. 20); see, however, Ref. 33.

| 33 TUM alumni holding professional positions provided a critical assessment of their acquired competencies in interdisciplinary and intercultural exchange and of project organization/teamwork; cf. also Global Challenge Insight Report "The Future of Jobs" (World Economic Forum, 2016).

great number of BSc/MSc programs (45/109) is subject to reduction, in favor of cross-departmental "Integrative Study Programs" – *role model*: Engineering Science (BSc) developed by MSE in 2010. Here the overall strategy will set the scene for a historic paradigm shift (A.3.2.2), which will be followed up on the European level by the EuroTech Universities Alliance (p. 11).

Table 5: Performance dimension Teaching: SWOT analysis

STRENGTHS

- Research-related study programs; broad-spectrum coverage of disciplines
- Constructive participation of students in course design
- Multiple cross-references to professional practice (adjunct professors, industrial internships)
- Competence-oriented programs aligned with objectives of competence
- Clear teaching strategy; holistic systematic QM processes established
- Internationalization, entrepreneurship, innovation: advanced implementation in MSc studies
- High foreign mobility of students (#1 Ger./Erasmus), high proportion of foreigners (30 %)
- Long-standing proven procedures for student selection (since 1999)

WEAKNESSES

- High number of students, inadequate teacher/student ratio (Prof/Student 1/75)
- Predominantly department-related course offerings: partially incoherent, overlapping, or redundant programs; only few cross-departmental "Integrative Study Programs"
- Inadequate involvement of professors in modern teaching formats
- Inadequate continuous academic education of scientific staff

OPPORTUNITIES

- Talent-oriented, individualized teaching with new competence profiles favoring social added value through education reform, integrating humanities/social sciences, data science, and new technology fields
- Development of transdisciplinary teaching formats and project-oriented teaching (MCTS, GOV/HfP, TUM School of Management): unique position of TUM in the technical disciplines achievable in the medium term
- Use of modern forms of teaching integrating digital teaching and learning technologies in the phase of self-directed learning (blended learning concepts); media-oriented learning spaces: increases training efficiency, creates space for humanities/social science content and new fields of technology; see A.3.2.2.
- New formats for the entry phase of studies to gain increased student success rate

THREATS

- Rigid university legal obligations and rigid structural requirements of the KMK
- Rigid regulations for teaching workload (except Tenure Track faculty); obstacle to design of modern teaching formats and academic continuing education
- Inertia of established stakeholders and traditional input-oriented proposals for subject-specific qualification frameworks: obstacle to design for new teaching contents and formats

b) Transfer

The transfer of knowledge and technology is part of the basic disposition of TUM, which is known not only for its research achievements (rankings A.2.2.1), but also for the implementation of *scientific inventions* in *commercial technological innovation*. This justifies the entrepreneurial claim of TUM (SWOT analysis Table 6).

Founding of start-ups: top place in Germany (p. 13); > 70 spin-offs 2017, 550 patent applications 2012–2017; > 7.5 M€ IP revenue 2013–2018. – *Reinforcement*, p. 37f.

Business cooperations: research volume 280 M€ (2012–2017), see Table 6.

Executive education: management training (business), > 500 persons per year.

Transfer and regional integration: (a) Campus Heilbronn (2018) with the opportunity to exploit one of Germany's strongest high-tech regions for TUM, cf. p. 7f. – (b) Campus Straubing (2001, extended 2015): Renewable resources, biotechnology, bioeconomy, sustainability as overarching teaching/research profile.

International transfer: (a) Liaison Offices in Africa (Cairo), Asia (Mumbai, Beijing), Americas (São Paulo, San Francisco), Europe (Brussels). – (b) Campus Singapore (2002): teaching/research programs, > 250 graduates (2017), currently > 80 TUM doctoral candidates.

Transfer into the school system ("backward integration") in many forms, including a school network with 48 reference secondary schools; cf. p. 5.

Table 6: Performance dimension Transfer – Entrepreneurship: SWOT analysis

STRENGTHS

- Distinctive regional, national, and international networks
- Excellent entrepreneurial spirit and reputation (founding university #1 Ger.), distinctive student founder culture
- Dense industry/spin-off network in an entrepreneur-friendly environment
- Regulated, self-confident IP policy
- Professional management of science/business cooperations (TUM ForTe, SVP Research & Innovation), > 1,000 contracts p. a.
- Associated institute *Unternehmer*TUM GmbH (Center for Innovation and Start-ups at TUM; > 140 employees) as a strategic competence partner located on the Garching Campus

WEAKNESSES

- Incomplete identification of patentable inventions; underdeveloped IP awareness
- Lack of incubators with well-equipped laboratories for chemical and biological/biomedical developments
- Academic continuing education program currently available only in management

OPPORTUNITIES

- Increasing availability of venture capital in the European Metropolitan Region of Munich
- European impact and visibility through planned London branch (p. 50)
- Enhanced alumni relations through academic continuing education (p. 38)

THREATS

- High rental prices for laboratories, workshops, and offices in Munich
- Outward migration through strong start-up funding elsewhere (e. g., London, Paris, Zurich)
- Insufficient industry/employer inclination for continuing education in technical disciplines

The associated institute *UnternehmerTUM GmbH* (founded 2001) and the *Center for Digital Technology & Management* (CDTM; founded 1998, TUM/LMU) provide assistance through teaching and start-up consulting. In the new building of the *TUM Entrepreneurship Center* (cf. ExIni II), entrepreneurship research, theory, and practice meet in a convincingly unique national position, with potential for internationalization.

c) Research infrastructures

The high, constantly increasing construction and building investments (A.2.1.4) reflect both the expansion and performance of TUM. On the Garching campus alone, approximately **480 M€** have been invested for **new construction and renovations** since 2003; around **115 M€** university-wide in **apparatus infrastructure** from state funds (2012–2017). In the future, the **"TUM Technology Core Facilities"** (p. 53) and accompanying measures for the 2019 Clusters of Excellence will be strategically relevant. For the most important infrastructures in the context of profile forming, see Table 7.

Table 7: Profile-supporting research infrastructures of TUM, cf. Appendix C.5.1/2

Bavarian NMR Center: 12 NMR spectrometers 300–950 MHz; 1.2 GHz-spectrometer (with HMGU) • **Bavarian Center for Biomolecular Mass Spectrometry**: 10 high-end MS systems with bioinformatics platform, DFG large equipment 2.9 M€/2018 • **TUM Electron Microscopy Core Facility**: infrastructure (2 SEM, 3 TEM) for biological and materials science (soft matter) and "in situ/operando" (hard matter) applications • **Munich Compact Light Source** (MuCLS, 2015): first mini-particle accelerator worldwide for brilliant X-rays to investigate biomedical research questions (MSB) • **TUM Mößbauer Technology Center** as a bundled portfolio of physics instruments, e. g., imaging & detector technologies • **TranslaTUM**: Center for Translational Cancer Research; core facilities: imaging – preclinical core – cell analysis – genome sequencing • **Research Neutron Source Heinz Maier-Leibnitz** (FRM II): TUM corporate research institute (joint federal/state funding). Scientific use as **Heinz Maier-Leibnitz Center** (MLZ) in cooperation with Helmholtz Jülich/Geesthacht, MPG, several universities • **Multiple Sclerosis Research Center** (foundation), in planning • **TUM Model EcoSystem Analyser** (TUMmesa): DFG research infrastructure (8 phytotrons for experimental ecophysiology) • **ZIEL Institute for Food & Health**: Central Institute for Molecular Nutrition and Health Research. *Core facilities:* microbiome (next-generations sequencing, gnotobiology); human studies (intervention studies, human phenotyping) • **TUMCells**: TUM/Helmholtz cooperation platform for GMP-based manufacturing, testing/approval of innovative somatic cell therapeutics, gene transfer drugs, tissue preparations.

A.2.2.3. Excellence of researchers and framework conditions

The outstanding scientists on the international stage (Appendix C.2.4) hold numerous high-ranking awards (A.2.2.1 and Appendix C.2.6) and distinguish themselves through their formative, reputational influence on their discipline, combined with international research presence and visibility.

Nevertheless, the academic scope of excellence cannot be limited to this: Excellence also encompasses the dimension of societal and economic or industry-related impact, which often has its own assessment criteria because of specific regional, national, or continental characteristics[34]. Consequently, a differentiated approach is required to assess the performance profiles in the very different subject cultures of TUM in an adequate and fair manner. This bold approach likewise guides the selection of the TUM Emeriti of Excellence, who measure themselves by their own subject-grounded excellence dimensions of inspiration and innovation. At TUM, the long-term stable overall performance is always part of the understanding of excellence. The **scientific performance nimbus of faculty** corresponds with the quantitative growth of TUM in all areas, cf. Fig. 1 / Table 1. A notion of the favorable, stimulating working environment can be expressed by saying that 80 % of the new recruiting attempts and 79 % of the retention negotiations were successful. Thus, TUM can count on a stable structure for its scientific top performers.

A.2.2.3.1. Promoting the excellence of scientists

With the unfortunate exception of academic mid-level staff (A.3.2.1.2), the systematic promotion of excellence applies to **all career levels**:

PhD candidates. They are all being supported, in a mandatory commitment as members of the TUM Graduate School (currently 6,380), in a structured environment where scientific knowledge gain is coupled with qualification for the labor markets: supervision agreements, transferable skills training, mentoring/networking, international exchange. – **Postdocs**, cf. A.3.2.1.3. – **TUM Junior Fellows** (since 2007). These young talents (currently 47, Table 1; postdocs/habilitation candidates) have made their mark competitively with their own research programs (e.g., DFG Heisenberg/Emmy Noether, AvH Kovalevskaja), are fully integrated into the faculty, exercise the right to award doctorates seriously, and receive additional support from central TUM funds. – **(Tenure Track) Assistant Professor** (since 2012). As independent faculty members, they have individually defined equipment and staff (≥1 scientific position, ≥ 150 K€ budget) in order to qualify for advancement in the faculty. *Supporting measures:* Mentoring Team, TUM Tenure Track Academy, performance interviews and status assessments for guidance, family-related support. – **Associate Professor.** Internal promotion in the TUM system (or direct recruitment from outside). Criterion: promising scientific potential for the future. Permanent W3 position. – **Full Professor.** Internal promotion in the TUM system (or

| [34] An architectural historian such as Prof. W. Nerdinger (TUM EoE) may not receive much attention on the international stage, yet his research on the architecture of the Nazi regime is nevertheless of great (social) political relevance and constitutes a unique expertise at our institution. Another faculty member, who should not go unmentioned here, is "Smart Farming" pioneer Prof. H. Auernhammer (TUM EoE), who was not recognized in his time.

direct recruitment from outside). Criteria: internationally recognized top-level research; innovative transfer capabilities (especially for engineers); clinical excellence (Medicine). – **TUM Liesel Beckmann Distinguished Professor.** Recruitment program for *female* professors of excellence, accentuation of the TUM gender policy, p. 36. – **TUM Emeritus of Excellence.** cf. p. 36. – **TUM Distinguished Affiliated Professor.** Currently 51 highly recognized international scientists. – **TUM Adjunct Professor (Honorary Professor).** Currently 156 lecturers active in teaching from professional practice.

The **career advancement** of permanent W2 professors ("extraordinarius" professors) with outstanding achievements leads to a full professorship as a **"lighthouse appointment"** (e. g., H. Dietz, Leibniz Prize; E. Resconi, CRC speakership)[35]. International top scientists are typically recruited via headhunting, some to AvH Professorships. External attempts to lure away excellent members of the TUM faculty are countered with convincing retention offers, cf. Table 1.

Tab. 8: Enhancement measures for faculty appointment

Efficiency of process and outcome. Fast-track appointment (5 months), aligned with standard international recruitment periods. **– Professionalized feedback to TT professors.** Coaching of mentors, introduction of "Faculty Challengers" for constructive criticism to discover untapped development potential **– International top-talents.** Proactive talent selection by search committees through the international network of experts (IAS Fellows, TUM Distinguished Affiliated and Visiting Professors, TUM Ambassadors), through "Talent Spotting" at specialist conferences and systematic screening by the President's office (database research)[a]. **– Joint Appointments.** Joint appointments with scientific institutions (MPG, HMGU, FhG, Imperial College London) and industrial partners. **– Onboarding of new appointees.** Overcoming barriers to integration: Dual Career Service (continuation MDCO 2.0) • Relocation Services (housing, government agencies, language courses) • Family Services (child care, international school options, holiday programs) • Recruiting & Career Services (junior researchers) – Acceleration of scientific working ability: Prelude 2.0 (Welcome & Information Day, Research Opportunities Dialogue) • Entry Training (Needs Assessments, Coaching Programs) • Jump-Start Management (individual assistance in setting up the professorship).

| a) **Criteria:** Success in highly competitive research funding programs, prizes/awards, publication output based on citation/network/technology analyses, science communication contributions.

Joint strategic fields with non-university research (MPG, HHG, FhG, Leibniz) are staffed through **joint appointments** (currently 51). In this way the scientific radius of action becomes wider for both sides; at the same time the international impact gains when it comes to forming focus areas.

| 35 **Criteria:** High-ranking scientific prizes or awards (e. g. Leibniz Prize, German Future Prize) • Highly competitive independent research programs (e. g. ERC Advanced Grant) • Spokespersons of CRC/TRR, EXC, FET Flagships or equivalent collaborative research projects • External offer as full professor at a renowned university or research institution • Contribution to profile developments of TUM.

The **personnel planning** relies on the well-balanced role model of the TUM Faculty Recruitment and Career System[2]. It will be supplemented in the future by systematic human resource (HR) development, of the so-called academic “Mittelbau” or mid-level staff (A.3.2.1.2) and the upgrading of administrative staff in terms of service orientation, digitalization and internationalization (A.3.2.5.3).

International appointment policy. As a result of effective, strategic decisions – Interactive Appointment Management (2007) • TUM Faculty Tenure Track or Executive Search (2012) – the appointment policy can now be elevated to the next level employing the enhancement measures in Table 8. In addition, the **cross-departmental TUM Appointment and Tenure Board** (ATB, cf. Appendix C.7.2) composed of highest-ranking scientists (10 TUM + 1 MPG), a distinctive feature Germany-wide that carries out the comparative quality assurance of all Tenure Track appointments, will in the future be employed in *all* faculty recruitment procedures[2] to ensure still higher, coherent quality standards in appointments.

A.2.2.3.2. Special measures for the promotion of excellence

TUM has established incentivizing programs in literally all performance dimensions in order to further advance and stabilize excellence (see also the planned extensions under A.3.2; international BSc students, see p. 33 Ref. 42).

Incentive Program (TUM Seed Fund) for the development of: DFG CRCs/TRRs (100 K€ per proposal plus reduction in teaching load of up to 7 contact hours/1 semester) • Research Groups, Research Training Groups, and Priority Programs (25 K€ per proposal, teaching reduction up to 3 contact hours/1 semester) • ERC Grants (up to 50 K€ per proposal, up to 7 contact hours teaching reduction/1 semester) • *coaching program and assistance* for applicants for ERC Grants (TUM Talent Factory) • *Equal opportunity* (coaching, training, mentoring, Laura Bassi Prize for outstanding female scientists, Paula Hahn-Weinheimer Prize to bridge-finance female postdocs) • *TUM Science & Study Center Raitenhaslach*: special grants for all newly recruited faculty (since 2016) to promote international exchange (symposia, etc.), currently 550 K€ p. a. allotted from TUM and foundations.

By virtue of a **straightforward Gender Policy** and measures related to it (extension see A.3.2.1.5), TUM has become ***attractive to females*** at all levels, quite untypical for a German technical university: faculty overall: **18 %** (Fig. 3), TT-faculty **38 %**, MSc students/PhDs/postdocs **32/37/39 %** (Fig. 3), Deutschlandstipendium **50 %** (quote enacted by President), TUM University Foundation Postdoc Fellowship **50 %**, executive administration **56 %**, TUM Board of Management **33 %**, TUM Board of Trustees **30 %**.

A.2.2.3.3. Performance-effective target criteria

Put forward in ExIni II (including Gender Policy), the target criteria that indirectly affect all excellence performance dimensions have been reached (status as of 2017). They are subject to continued improvement on the TUM AGENDA 2030 (Fig. 3), thus heading to an *international and more female university*.

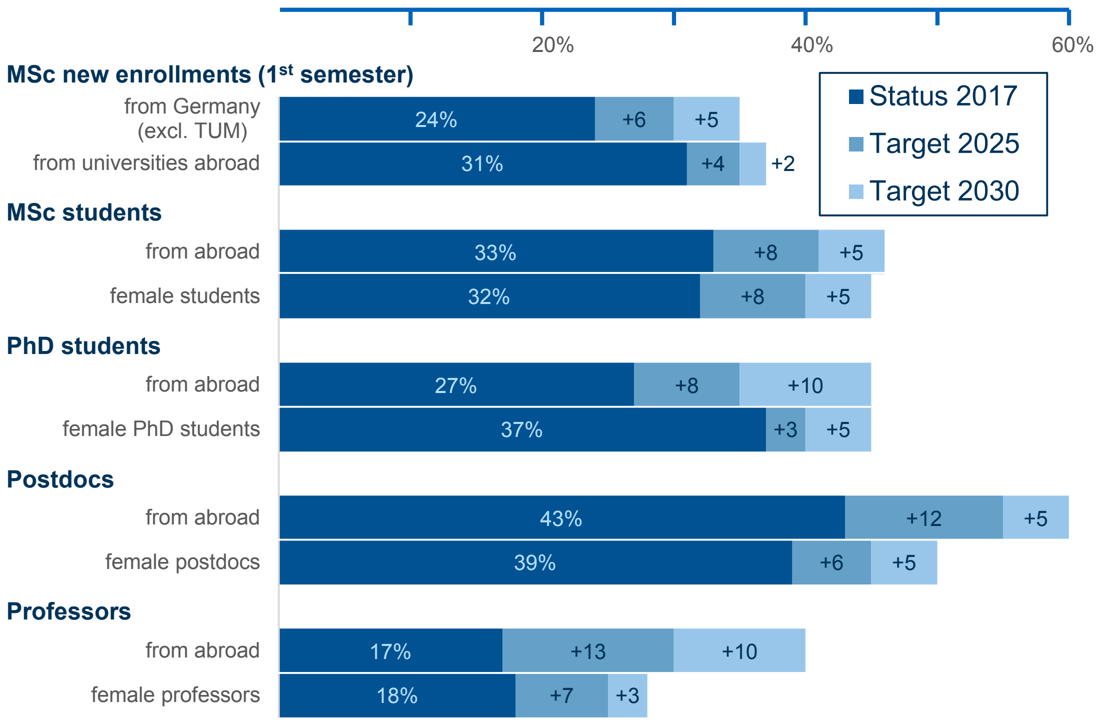

Fig. 3: Key performance-related targets envisioned in the TUM AGENDA 2030 for the years 2025 and 2030, respectively, based on the 2017 Status Quo (all numbers in % of total).

A.2.2.3.4. Quality assurance, cf. A.3.4.

Peer-review evaluation of the departments and other scientific units, performed every 6 years, has become accepted best practice at TUM. A seamless proven QM system is in place. The planning, implementation, and evaluation follow the proven ***principles of agile project management*** to permit timely iterative adjustments in case of changed conditions or unintended effects (see below). The involvement of all project stakeholders ensures transparency and accountability. For all measures, concrete work packages with milestones are defined according to the ***PDCA circulation principle*** (Fig. 4).

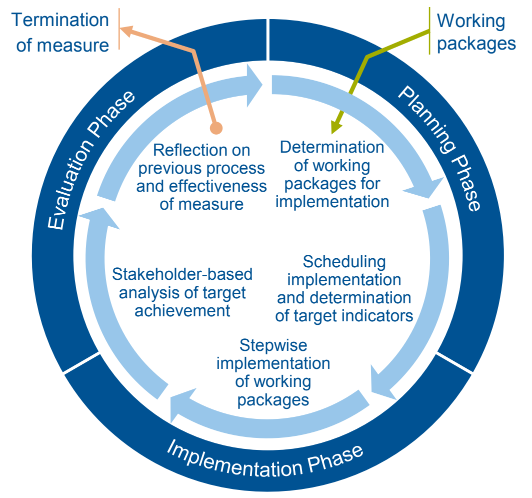

Fig. 4: Circulation principle for TUM's internal quality assurance

A.2.2.3.5. Unintended effects

In the past 20 years of reform at TUM, unintended effects, which each strategy is generally faced within implementation, were either exploited in a beneficial way or, – in the case of counterproductivity, – were used for realignment of measures. Potential-directed assessments, including participation from relevant areas,[36] led to adjustments or redefinition of initial goals. The examples in Table 9 stand for a fair number of measures that were administered as a result of positive or negative events of (e.g., conflicting targets) to ultimately meet the strategic outcome, or even exceed it – such as MCTS, p. 45.

Table 9: Handling of unintended effects: Selected examples from ExIni I/II

Measure	**Unintended effects:**	+ positive; -•- neutral; - negative
MCTS	+	a) As a result of MCTS (Social Sciences): Bavarian Parliament transfers Hochschule für Politik München[6] from LMU to TUM (2014) and endows it with resources (6.1 M€ p. a.).
	++	b) New department (TUM School of Governance) established: institutional anchoring of political science at TUM (2016), p. 45.
Faculty Tenure Track	-•-	a) TT: under university law, no feasible advancement model for permanent W2 ("extraordinarius") professors
	+	b) "Lighthouse appointment" option for highly qualified talents[3]
MSE	-•-	a) Nationwide demand for regulation of PhDs at Universities of Applied Sciences
	+	b) MSE as the archetype for the development of a *Bavaria-wide model* under TUM leadership (BayWISS, 2016)
TUM-IAS	-	a) Lack of widespread impact within TUM due to rigorous demands for excellence
	+	b) Establishment of thematic, profile-strengthening TUM-IAS Focus Groups; scientific dialogue with faculty members
Anna Boyksen Diversity Research Center	-	a) Repeated failure in search of internationally prominent diversity research leader
	+	b) Systematic transformation of TUM-IAS Senior Fellowships for diversity research with multiple references to departments; preparation for Diversity Research Center
Entrepreneurship	-	a) Poaching of well-trained TUM personnel by industry
	+	b) Cross-disciplinary personnel deployment; *in the future*: career program for mid-level academic staff, A.3.2.1.2 p. 34.
TUM Vision 2020	-•-	a) An extensive review process did not reveal a meaningful transformation of TUM into an ostensibly more efficient legal form.
	+	b) The School System (A.3.2.5.1, Fig. 8, p. 52) emerged from the review process "TUM Vision 2020" (ExIni II).

| [36] Professors, staff, students; faculties, evaluation and ad-hoc commissions, advisory boards, QM-circles, University Council/Senate, State Ministry of Science and the Arts.

A.3. Plans and potential

After two decades of an active renewal policy accompanied by far-reaching reform steps, TUM is now, in the 150th year of its existence, setting forth a rigorous **overall strategy** to move beyond a top position nationally (p. 13)[18,19] and ascend to the **international top league** in the medium and long term. Given TUM's self-image as an inspiring "servant of society," the interdisciplinary performance domains of *education* • *research & innovation* • *promotion of young talent* • *transfer/entrepreneurship* are equally important to the university. The "Entrepreneurial University" mission statement is not limited to the transfer of knowledge and innovation, but lives in the university family as a basic attunement to a progressive readiness for change.

It is generally recognized that international competition in the **age of digitalization and biologization** is changing in science, business, and society at an unprecedented pace. TUM has a stable performance spectrum, giving it the security to set a new, sustainably effective renewal dynamic in motion to increase both the power of scientific innovation and the inner coherence of the university family. The *Institutional Strategies 2006/2012* offer plenty of room for differentiation; however, they require a far-reaching and vital overall strategy – including new performance dimensions – with new, interactive fields of action. This approach inspired the TUM AGENDA 2030.

A.3.1. Strategy and objectives

The intrinsic deficits typical of the German higher education system are to be overcome at TUM by means of the following **five guiding objectives**:

1. **Gender- and diversity-equitable talent management**, from talent-led student selection to consistent career development for science staff to well-structured continuing education and advanced training with both inward and outward impacts (TUM Institute for Life Long Learning);
2. **Future-oriented vitalization of "German Engineering,"** which as a result of "disruptive" scientific advances, structural economic changes, and societal paradigm shifts, faces historical challenges that are crucial for the future of Germany as a technology location, making the powerful development of technology-minded humanities and social sciences (including political science) indispensable at a truly modern technical university (*"Responsible Innovation"*);
3. **Dynamization of scientific interactivity** through interdisciplinary measures that transcend subjects and departments (e.g., TUM Integrative Research Centers, TUM Institute for Data Science, Technology Core Facilities) in powerful alliances, primarily in the Munich metropolitan area;

4. **Empowerment of the international network**, especially the off-shore locations abroad, in profile-strengthening teaching and research alliances (e. g. Singapore), with a return to the home continent of Europe and with renewed commitment to often-neglected Africa, a continent of the future;
5. **Renewal of university governance and administrative structures** in the context of system integration, internationalization, and digitalization (*"Structure follows Strategy"*).

These five major objectives are tied in with the achievements of the Excellence Initiative 2006–2017 through an inner logic. They already possess exemplary anchor activities, accompanied by proven profile-enhancing and sustainable areas of research (A.2.2.1.1/2). The measures not only sharpen the identity and value of the **TUM brand**, but also mobilize the prominent science and business region of Munich.

The **strategy formation and adjustment** are based on the Institutional Strategies (ExIni I/II, 2006/2012), which were transparently implemented and have since become pervasive in the living practice of the university. Results such as failures, newly identified deficits, and supplementary or corrective needs give rise to experience-based, participative consultation and dialogue forums on all operational levels, always including external expertise. The participation of the university community has contributed significantly to the emotional coherence of the TUM family, now encouraging a far greater reform effort aiming at *Innovation by Talents, Excellence, and Responsibility*.

Certainly, the renewal domains 1–5 (see above) can only be realized on a large scale in a long-term overall strategy (TUM AGENDA 2030 with near-term targets 2026). The key objectives bundle the core desiderata of the SWOT analyses (Tables 3, 5, 6) but do not leave behind potential conflicts between goals or recognized issues due to previously low priority. Where development fields are not yet ripe for key contributions to the overall strategy, appropriate measures are taken[37].

It speaks in favor of the **persistence of renewal at TUM** that former developmental "laggards" – Life Sciences Weihenstephan (1928)[38] or Medicine (1967) – after profound reform processes (WZW: 1997–2012) and structural measures, help significantly to shape the overall performance level today. This also applies to TUM.Asia in Singapore, the only enduringly successful international campus of a German university. The proven sequence of *site development – structural integration* (into the overall portfolio) is now

| 37 For instance, the chronically research-weak Sport Science (since 1972) – responsible for all sports students (ca. 2,600) of the Munich universities – is massively expanded (+6 professorships, new construction 144 M€) and intertwined with nutrition and medicine to build a competitive health sciences profile (prevention).

| 38 The upward trend in recently low-demand agricultural sciences is being promoted via the instrument of *Target Agreement* (2.7 M€ p.a. 2018–2022; TUM – Free State of Bavaria).

being applied to the new Straubing and Heilbronn locations. One example of the connectivity of once "subordinate" subjects is Architecture, which is shown by the synergistic approach of TUM Technology Design (A.3.2.3.6).

Although TUM has substantial experience with reform processes and strategic adjustments, the Board of Management – together with the senior management level of the Deans – remains committed to change management that is transparent, communicatively candid, and motivating. The structured follow-up on change effects by evaluation is part of this. Overcoming old paradigms sometimes requires transitional measures to get the university community and professional practice on the path to the new goals. Resolving conflicts between goals – for example, small-scale, specialized *vs.* interdisciplinary, cooperative teaching or research formats ("networked world") – can contribute to clearing up undesirable developments.

A.3.2. Planned measures and anticipated effects

The ***five key objectives of the overall strategy*** are interlinked in terms of their operative components and, in terms of content and structure, are based predominantly on well-proven best-practice approaches at TUM.

A.3.2.1. Gender- and diversity-equitable talent management

Diversity, understood as "diversity of talents" under the principle of equality, is anchored in the mission statement as well as in day-to-day practice[39]. Diversity and talents belong together at a top university. The following measures should contribute to a holistic, diversity-oriented talent management (see also Fig. 3 p. 29).

A.3.2.1.1. Selection and promotion of students

To ensure that students' *gifts and inclinations* match TUM's *offer and standards*, an aptitude test based on the requirements of "qualified interdisciplinarity" will be carried out *across the board*; this is indispensable in light of the massive influx of applicants from Germany and abroad[40] (Fig. 1, Fig. 3). Here TUM draws on the most comprehensive experiences to be found at any German university[41]. It is not just about attracting as many students as possible, but about winning the *best-suited students*, who are then promoted individually and in talent-oriented program lines[42], cf. p. 43ff. and p. 53.

| 39 **Overall coordination:** SVP Talent Management & Diversity (since 2011). – Anchoring Diversity in the TUM Mission Statement (2008) • TUM Diversity Code of Conduct (2012) • Diversity Charter (2007) • target agreements with departments/central (since 2012) • ExIni Institutional Strategy (2006/2012).

| 40 **New matriculations 2018:** 13,214 (+ 34 % *vs.* 2012, +109 % *vs.* 2007). – Newly enrolled *foreign* students 2018: 23 % in BSc/47 % in MSc programs.

| 41 **Balance sheet:** "Studied successfully? Results of a quantitative cohort analysis" – TUM 2017.

| 42 **TUM:*Junge Akademie:*** 501 funded students 2010–2018; approx. 4,950 incl. Deutschlandstipendium (2011–2018; *from 2019*: increase by 300 p.a. for international BSc students).

A.3.2.1.2. CareerDesign@TUM: Mid-level academic staff – personnel development

Encouraged by the successes of the new recruitment and career system (p. 4)[2], TUM is going to tackle one of the *"central challenges for the German science system"* (WR 2017): the systematic development of qualification and career paths for the so-called Mittelbau (mid-level academic staff).

Concept, measures. CareerDesign@TUM, a first in the German university landscape, applies to the valuable but insufficiently used talent pool of (currently) around 450 permanent employees (+ 300 incl. hospital) in the academic service[43]. As the **key personnel policy project** of the overall strategy, a graduated qualification system is set in motion that opens **five career paths** to mid-level academic staff for the most common fields of activity[44] (Fig. 5):

① **Scientific Service *(TUM Researcher)*:** activity in the immediate environment of professorships, such as research participation/coordination, applications for third-party funding, reduced teaching load, science-related administration.

② **Academic Teaching *(TUM Lecturer)*:** activity as an autonomous lecturer or "Instructional Designer" integrated into defined teaching units (TUM Professional Profiles, A.3.2.5.1.4), with contributions to research-oriented teaching.

③ **Science Management *(TUM Science Manager)*:** activity in the supervision of scientific support units (e.g., management of schools/departments, research clusters), central university services (e.g., Faculty Recruiting, TUM-ForTe, International Center, Graduate School, TUM EdTech Lab).

④ **Innovation and Spin-off Management *(TUM Entrepreneurial Advisor)*:** activity in promotion of up-and-coming entrepreneurial talents in preparation/implementation of start-ups in the technology sector.

⑤ **Scientific-Technical Operations *(TUM Technical Expert)*:** activity in the operation and further development of apparatus infrastructures (e.g., large-scale machines, TUM Core Facilities), technology transfer (e.g., standardization, industry consultation), technical testing institutes/central laboratories, IT centers, TUM Institute for Data Science (cf. A.3.2.3.5).

The **three-level career model** (Fig. 5)[45] leads via assessment, coaching, mentoring, and qualification programs to the differentiation of individual interests, talents, and application

| 43 Plus ca. 4,400 (excl. university hospital) temporary employees outside the Tenure Track.

| 44 Interview study by SVP C. Peus (2012) and quantitative survey with 363 participants (Task Force on Competence Profiles, K. Diepold, 2014).

| 45 For **CareerDesign@TUM**, there is a binding set of rules that makes the levels of entry, qualification, promotion, and (if necessary) exit transparent. Quality assurance is provided by a mentoring program. – Qualification program: TUM-IL[3] (A.3.2.1.8).

areas, taking into account the employee's life situation (e. g., family, full/part-time employment, leave/advanced training/retraining phases). Each level is associated with the acquisition of professional competences, leading to a certificate: ***Entry/basic level:*** focus on expertise in the subject area • ***Promotion phase:*** plus management education • ***Senior level:*** plus leadership competence. – For the attendance period, the **TUM Science & Study Center Raitenhaslach** is being developed to become an **Academy for Human-Resource Development** (goal 2026). Advanced training and further education are continuous throughout levels and careers (Fig. 5). – **Requested resources:** Integrated into the TUM Institute for Life Long Learning (IL³) (A.3.2.1.8).

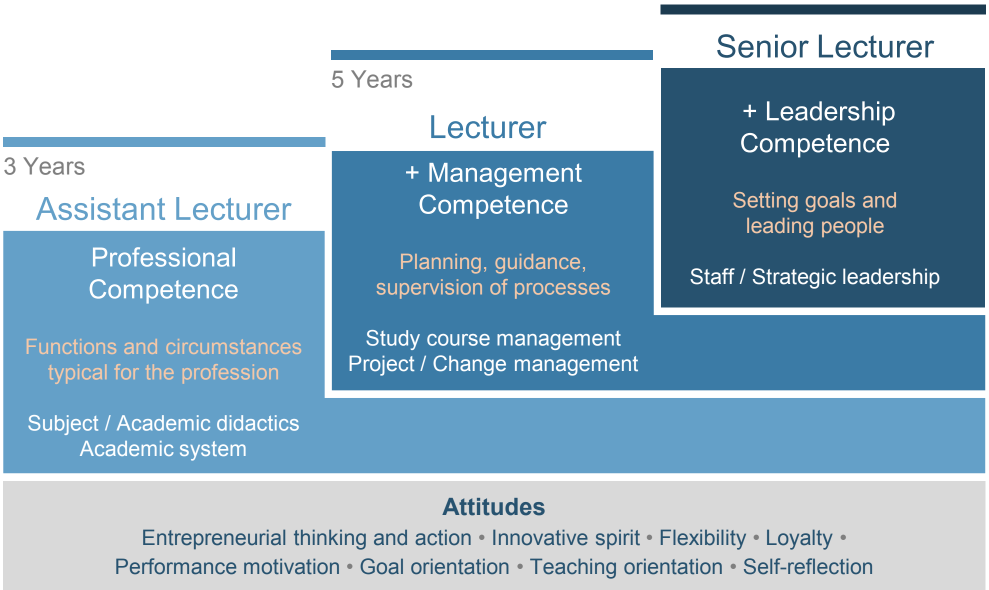

Fig. 5: CareerDesign@TUM: Careers for mid-level academic staff (Career path "TUM Lecturer")

A.3.2.1.3. Connection of homeland and the world: Academic internationality

MSc students. Through a competitive fellowship program – co-financed as Deutschlandstipendium by KMvB and the TUM University Foundation – *300 excellent students from abroad will be admitted into MSc programs each year*; that is, 600 scholarships annually from the second year on (annual investment 2.16 M€).

Postdoctoral researchers (TUM.Global Postdoc). They are a best-practice key factor because their relevant research experience, typically acquired abroad, is seamlessly connected to TUM. Germany can't keep up here, despite having the AvH Foundation and the DAAD[46]. Consequently, TUM runs its own international postdoc program (Research Opportunities Week, ROW • TUM University Foundation Fellowships, 2012), which beginning in 2019 will be doubling the number of fellowships from 15 to 30 annually and changing from 1-year to 2-year support (3.9 M€ p. a.). In addition, the TUM-IAS will make 5 competitive postdoctoral fellowships per year (2-year, AvH-level) available to

[46] **International benchmark universities** are numerous, i. a. Cambridge/UK: > 2,000 Postdocs (TUM: 577).

enhance its Focus Groups. **– Requested resources:** 100 K€ p. a. material expenses for 2 ROWs; 5 TUM-IAS postdoc fellowships at 80 K€ p. a.

New appointments. Cf. strengthening measures (Table 8), particularly for acquisition of international top-level talents along the lines of existing role models (e. g., Kéré AR, Cheng EI, Kramer EI, Fornasier MA, Sharp PH, Resconi PH, Moretti ME, Rixen MW).

Visiting professors. Through the *August-Wilhelm Scheer Program* (since 2014)[47], 112 visiting professors from 34 countries (i. a. MIT, Harvard, Cornell), 61 in the engineering sciences, have come to TUM. In the future, visiting professors will be integrated into teaching/research operations and will be authorized to conduct examinations. **– Requested resources:** 400 K€ p. a. personnel and material funding for 2 rounds of invitations.

TUM Ambassadors. Highly successful in its multiplier effect (ExIni II), the program for the acquisition of renowned international scientists as "ambassadors of TUM" is being expanded from 124 to 180 (goal for 2025) using university funds.

Alumni. Cf. TUM.The Open University Initiative, A.3.2.1.7.

A.3.2.1.4. Capitalizing on valuable experience: TUM Emeriti of Excellence (EoE)

This college of outstanding emeriti (currently 66) has proven to be a highly supportive loyalty factor for TUM (ExIni I). In the future, TUM will open a working environment for selected members, holding their own third-party research funds, as **"Senior Excellence Faculty"** integrated into TUM-IAS. **– Requested resources:** EoE Incentive Fund 100 K€ p. a. (conference travel) • 2 scientists (for 2 Senior Excellence Faculty p. a., 3 years with extension option) • Managing Director EoE: TUM Budget.

A.3.2.1.5. Diversity of Talents: Gender- & Diversity Policy

Consistently developed over two decades, the Gender & Diversity Culture has, not least, promoted top-level research at TUM. The wide-ranging bundle of measures became effective on all working levels[48]. Beyond previous signal effects, the diversity policy on the TUM AGENDA 2030 is now gaining *overall strategic significance:*

"Angela Molitoris[49]" – The TUM 10 Million Program. This new bonus system is intended to make gender sensitization more dynamic throughout the university. Departments/schools receive special premiums for contributions to diversity policy, for goal-oriented purposes at their own discretion, in fact ***for each new*** appointment of a

| 47 Donor and TUM Distinguished Affiliated Professor. **– Objectives:** Internationality, diversity, top-level research, alliance formation with international partner universities. – **Investments** so far 1.75 M€.

| 48 **Indicators 2017:** 35 % female students (2005: 30 %) • 18 % female professors (2005: 7 %) • 50 % women among "Deutschlandstipendium" holders • 40 % female students in BSc study program "Environmental Engineering."

| 49 **Angela Molitoris**: first female head of administration (1971); **Liesel Beckmann**: first female professor (1941); **Anna Boyksen**: first female student (1906); **Amalie Bauer**: first female PhD (1918) of TUM.

female professor: 100 K€ • speakership of a female professor in DFG CRCs/TRRs or comparable research alliance: 60 K€ • female honorary/visiting professor: 10 K€ p. a. – For “Angela Molitoris” 10 M€ are allotted for 2019–2026 from university funds.

Liesel Beckmann Distinguished Professorship[49]**.** The appointment program (since 2012) is being revitalized to accentuate again and again the visibility and impact of top female scientists (goal 2025: 18 %) beyond their own disciplines[50]. – **Anna Boyksen Fellowship**[49]. The program for top-level female professors of gender and diversity studies will be doubled to 10 Fellowships to lend weight to these thematic TUM-IAS Focus Groups. – **Amalie Bauer Fellowship**[49] for young female researchers (since 2017) in the humanities and social sciences (postdoc level). – **Honorary/Visiting Professorships.** The chronically weak proportion of women (11 %, “leaky pipeline”) will gradually be increased to 25 % by 2030 in accordance with the university-specific target (bonus model). – **Gender & Diversity Research.** 5 professorships will be newly established as joint appointments (IRCs/departments), at least 50 % to be held by women, participating in the “Responsible Research & Innovation” renewal program (p. 45f.). – **Diversity Competence.** The *Gender & Diversity Incentive Fund* for the departments and the training courses on diversity competence (teachers and students, ExIni II) will be continued. The successful “Tandem Call Procedure” of the TUM-IAS (p. 47) will be made permanent in order to maintain the achieved 50 % quota of female fellowship holders (2013: 23 %). *Mandatory* Gender & Diversity *On-line* Coaching is being introduced for all new recruits. – **Requested resources:** The overall package comprises ca. 4.1 M€ annually. Of this, 20 % is requested as a **Gender & Diversity Excellence Fund**, primarily to cover expenses associated with professorships (*female* staff, travel, seminars/conferences in the TUM Science & Study Center Raitenhaslach).

A.3.2.1.6. Entrepreneurial Action: TUM*entrepreneurship*

Since 2011, the TUM*entrepreneurship* action concept has been proactively supporting the founding of growth-oriented start-ups.[51] Among German universities, TUM is the best at supporting start-ups (p. 13)[52]. By virtue of the **reinforcement measures** (Table 10), TUM aims to become one of the most successful launch pads for high-tech start-ups with potential for growth. For this, 50 % **funding** p. a. is **requested** for the following measures: 2 Incubator

| [50] **Appointed so far**: S. Maasen, J. Winkelmann, S. Hirche, S. Albers, E. Resconi, R. Hillerbrand; corresponding to 12 % of newly appointed female professors since 2013.

| [51] **Leaps in development success:** 29 →76 start-ups (2011 and 2017, respectively) • > 800 companies founded by TUM members since 1998 (currently > 15,000 jobs) • so far 8 TUM spin-offs listed on stock exchange, e. g., Celonis AG (founded 2011) > 1B US $ enterprise value (“Unicorn”).

| [52] **Founding Radar 2016 of the Stifterverband** and **German Start-up Monitor 2018** (p. 13). – The entrepreneurial spirit of MSc students and PhD candidates is activated by qualification programs such as *Think.Make.Start* and the *Global Food Venture Program*. Would-be TUM founders are in the lead in winning funding for technology-driven start-up projects (25 % of the 90 BMWi-funded EXIST start-up projects).

Managers • 4 Project Managers (Entrepreneurial Advisors, cf. CareerDesign@TUM p. 34) • external consultation (100 K€) • TUM Impact Fund (6 at 25 K€) • TUM Entrepreneurship Host (10 at 10 K€) • TUM Proof of Concept Fund (5 at 100 K€).

Tab. 10: Reinforcement Measures for Promotion of Start-ups [a)]

TUM Incubators, TUM Impact Labs. Expansion of the TUM Incubator Garching (ICT, MedTech, Robotics, Mobility)[b)] with focus on (Bio)chemistry/Biophysics, supplemented by TUM Incubators on the Munich Medical Campus (BiomedTech, Life Sciences) and Campus Weihenstephan (Food & AgroTech): project screening / innovation scouting, market potential validation, and, if applicable, development of clinical strategy, business plan, pre-seed/seed funding. Laboratory areas can be used as TUM Impact Labs for start-up initiatives and founders supported by a structured incubator program. **• IP Sensitization.** Partnership with European Patent Office Munich for advanced training of students/scientists on IP (workshops, lectures, exploratory events). Improved commercial exploitation of TUM patents through the use of external expertise (Ascenion, TTO, IMM, XimBio, etc.). **• Financial Support for Founding Mentors and Founders.** Incentivization of professors to support publicly funded start-up activities ("TUM Entrepreneurship Host") and the establishment of TUM Impact Labs ("TUM Impact Fund"). "TUM Proof of Concept Fund" for pre-seed promotion of highly promising start-up initiatives. **• International Networking.** International entrepreneurship, based on the successes of the European Venture Program and US Venture Program: Asian Venture Program (Singapore, Hong Kong/Shenzhen), African Venture Program (cf. TUM.Africa, p. 51) • TUM*entrepreneurship* Branch ("White City Campus," Imperial College London).

| a) **Organization:** TUM Incubators are set up by one executive each, supported by 2 operative project managers at the interfaces to TUM ForTe/UnternehmerTUM. – b) The **TUM Chemistry Incubator:** the first integration model of a department (Garching, 250 sq.m. highly equipped laboratories; from 2020).

A.3.2.1.7. Alumni in the Alma Mater: TUM.The Open University Initiative

Motivation. Since 1998, the alumni network TUM*net* has been built up around the globe on the way to creating a generation-linking university family[53]. In the next major step, TUM is opening its doors to alumni to provide them with appropriate further academic qualifications in times of changing job markets.

Goals, measures. Vitally anchored in the overall strategy, **Alumni@TUM** integrates alumni into life long learning as part of a comprehensive diversity concept[54]. This is the first time the university has actively tapped into this unique talent pool, which for the exam years 1992–2017 alone encompasses around 90,000 working graduates.

| 53 **TUM*net:*** at present > 81,000 former graduates are registered (Table 1). Active use for encounters and information exchange (e. g., alumni magazine KontakTUM, alumni surveys, scholarship support/mentoring, task forces, annual Advent Matinee in the Munich Philharmony, silver/gold anniversary diploma celebrations, homecoming parties, regional alumni clubs, e. g., China, fundraising). – At TUM, alumni are institutional members of the university (Basic Order).

| 54 **Benchmark universities** (selection): Yale, Chicago, Imperial College London, ETH Zurich, Alberta, Harvard, Stanford.

■ **TUM Institute for Life Long Learning.** See below, A.3.2.1.8.

■ **High Potential Alumni**. The "TUM Ambassadors" initiative (ExIni II, p. 36) will be extended to professionally experienced alumni.

■ **TUM*net***[53]. Digital expansion of the platform for mutual exchange of information and experience to include alumni in university development.

A.3.2.1.8. Learning at work: TUM Institute for Life Long Learning

Goals, measures, structure. Life long learning, combined with individual, in-service career development, will become a new, profile forming, strategic field (TUM AGENDA 2030). The new **TUM Institute for Life Long Learning (IL³)** brings all science-related continuing education and training programs together under one roof, enabling structural expansion and accommodation of new requirements (Fig. 6). Initial focus: young professors, mid-level academic staff, alumni; rapid expansion for general personnel development. The IL³ addresses its offerings to members of the university, including alumni **(Carl von Linde Academy)** as well as executives and technical experts from business and public organizations **(Executive Education Academy).** In the **TUM EdTech Lab,** serving as a "one-stop shop" also for use in regular teaching, digital training formats are being developed.

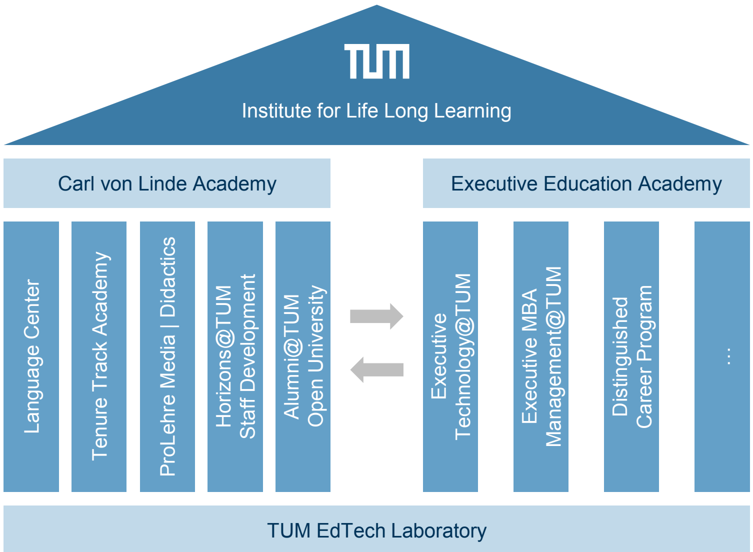

Fig. 6: TUM Institute for Life Long Learning (IL³)

■ **Carl von Linde Academy** (CvL). Integration of all internal school programs for professors, scientific staff, administrative personnel, and alumni (cf. A.3.2.1.2/ A.3.2.1.7) and offers to impart key competencies to students and doctoral candidates.

■ **Executive Education Academy** (EEA)[55]. It primarily addresses technical experts and business executives (currently ca. 500 p. a.). Previously limited to management training, continuing education programs will follow for working natural and engineering scientists who want to stay on top of newly "emerging technologies." It will also include TUM's faculty to train them in their **leadership abilities**[55]. The "Distinguished Career Program" applies to leaders aiming to prepare professionally for other types of work (e.g., business, politics, foundations).

| [55] Test phase in operation. – **"Triple Crown" accreditation** effect (2017): TUM School of Management as the preferred address for the training of subject-matter experts and executives.

■ **TUM EdTech Laboratory.** Available across the university, it develops digital education formats and organizes blended learning concepts tailored to TUM. It exploits the outstanding in-house potential in electrical engineering and information technology, informatics, robotics, medical and sports didactics, simulation technologies (virtual reality), economic and education sciences, TUM ProLehre Media&Didactics (digital teaching assistance systems). At the same time, TUM EdTech functions as the main training hub for future "Instructional Designers" who co-design and apply blended learning contents. TUM EdTech is also intended to develop as an incubator for technological spin-offs with digital teaching assistance systems.

Organization: Headed by SVP Talent Management & Diversity; internally/externally appointed Advisory Board. – **Quality management**: accompanying scientific research (EDU dept.); program evaluation (Advisory Board, annually); 5-year external accreditation. – **Requested resources**: IL^3 Managing Director, 3 Career Coaches; EdTech Lab: 1 W3 Prof. + 2 sci. staff (blended learning research), 1 IT specialist for blended learning, 2 IT technicians; 3 administration; 100 K€ material expenses p. a. set-up phase (2019 – 2021): + 300 K€ Investment (Infrastructure), + 100 K€ expenses for external experts, + 1 IT technician and 1 sci. staff (TUM EdTech Lab).

A.3.2.1.9. Community Address: TUM150 Anniversary Tower

Fig. 7: TUM150 Anniversary Tower (Design F. Kéré, TUM)[4], estimated cost 32 M €. Start of construction 2020, completion 2023.

Measure. The boisterous development of Garching campus, centrally positioned on the axis halfway between Munich and Freising, demands an urban accent that promotes the identity formation of the TUM family. Financed mainly by a foundation, a 9-story building with approx. 10,000 sq.m. of floor space (Fig. 7) will be built to provide an address for a central *Welcome and Information Center*, for the *alumni*, *TUM Emeriti of Excellence*, and *foundation facilities*, as well as the *TUM public dialogue forum* (Public Awareness of Science; MCTS/TUM-IAS/Deutsches Museum Munich), combined with "tangible" illustrative examples of cutting-edge research (IT-driven temporary exhibitions). *Science communication* is given a coordinating function with university marketing and the Corporate Communications Center (p. 57). One floor serves as a Digital Learning Space with the *TUM EdTech Lab* as well as an amphitheater area and rooms for cooperative learning in the attendance phases of blended learning (plug-in formats/academic continuing education, p. 39). A divisible *auditorium* on the top level (capacity 400 people), together with the *"TUM150 Campus Club"* (cafeteria, restaurants, TUM merchandising) should create a science-oriented meeting atmosphere that is attractive for all TUM groups and the public. **– Requested resources: -•-** (TUM University Foundation and KMvB Funding).

A.3.2.1.10. Expected effects

Gender- and diversity-equitable talent management anticipates mobilizing effects to the overall scientific performance on all levels. Typically, the **Angela Molitoris 10 Million Program** and related measures highlight TUM's ongoing gender and diversity policy. Unprecedented in Germany, **Career Design@TUM** unlocks new development prospects for mid-level academic staff by way of differentiated talent-responsive career paths, also improving professional mobility and opportunities for female employees. The **targeted focus on alumni** leads to an identity-enhancing bond with their Alma Mater, with mutual benefits in terms of diversity • interdisciplinarity • internationality • knowledge exchange. The pioneering **IL³ program**, contributing to a rigorous personnel development, is expected to trigger the timely **paradigm shift in university education** from "one-time studies" to **life long learning.** Backed by previous successes (Fig. 1), the heavily reinforced **TUM*entrepreneurship*** is set to make TUM Europe's leading spin-off university. **"Senior Excellence Faculty"** empowers TUM Emeriti of Excellence to continue on cutting-edge research and includes them in the overall strategy (e. g., TUM.Africa, quality management), thus unfolding their role model function for students and faculty.

A.3.2.2. "German Engineering" of the future

The proverbial "German Engineering," with its brilliant international appeal, is the innovation engine of the German national economy[56]. Its prominent hallmarks are precision, quality, durability, and reliability. The German engineering education focuses on problem-solving skills, is strongly product- and production-oriented, and takes into account the requirements of industrial practice. However, in the midst of the 4th Industrial Revolution, the world order and values system are changing in light of new social, political, and economic perspectives (energy, environment, climate, mobility, information, data security), as are the national, institutional, and individual spheres of action[57]. At a top university, in this highly dynamic environment, the classical engineer's paradigm of

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| 56 As one of the largest technical universities in Europe, TUM releases around 5,200 engineers into the professional world each year, of which 24 % female, 8 % PhDs, 29 % foreign nationality.

| 57 **Memoranda**: EUROPE 2020 – A strategy for smart, sustainable, and inclusive growth (EU Commission 2010). – The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution (World Economic Forum 2016). – Smart Germany: Engineering Training for the Digital Transformation (VDI, 2018). – The Engineers of the Future (Airbus, White Paper 2018).

product and service orientation[58] needs to evolve into *"Human-Centered Engineering"* and, through the *"Design Thinking"* approach, open up exploratory solution spaces for previously unformulated questions. It is necessary to steer the impulses of disruptive technologies (such as bio-inspired design concepts, new materials/resources, additive manufacturing, life-cycle management) along the path to sustainable innovation. Humanities and the social and behavioral sciences are gaining wide scope here (A.3.2.2.3). In this context, Stanford and MIT are role models.

A.3.2.2.1. Human-Centered Engineering and Future Design

Grounded in disciplines but interdisciplinary in nature, the concept of **Human-Centered Engineering and Future Design** takes on the "grand societal challenges" so flexibly that design-functional as well as political, societal, economic, and moral-ethical implications are taken into consideration. Consequently, beyond technical competence, the educational horizon of the participating actors becomes a crucial success factor. The **measures** leading "German Engineering" into the future are designed for short-, medium-, and long-term implementation:

■ **Expansion and integration of humanities and social and behavioral sciences.** See A.3.2.2.3/4.; new faculty positions: Ref. 61 and Table 12 p. 45.

■ **Redesign of education** (A.3.2.2.2, p. 43).

■ **TUM Institute for Technology Design** (A.3.2.3.6). Development of "Design Thinking" in both research and teaching as a methodology for user-oriented responses to complex questions with large solution spaces, by networking different specialist cultures *("Fusion of Knowledge")*.

■ **Governance** (A.3.2.5.1). Overcoming department-bound narrowing effects: *Schools* • *TUM Innovation Networks* as "scientific speedboats" • professionalized structures for the development of *competence profiles and curricula*.

■ **Appointment policy**. Basic and applied research characterize "German Engineering" in equal measure. *Competences in new methodologies* will have a vitalizing effect in both directions, particularly in the context of advanced theory formation (modeling/simulation, data and information processing, machine learning). This gap is being closed through an adjusted appointment policy (methodologically oriented professorships).

| [58] The engineering disciplines are essentially focused on the artifacts created (e. g., buildings, infrastructure, machinery) and thus are modeled on the associated industries. This traditional approach meets neither the expectations of today's students nor the competitive economic constellation of tomorrow.

A.3.2.2.2. Engineering education of the future

Consistent with the 2018 MIT study[59], TUM considers itself sustainable if it (i) provides **student-oriented teaching** optimally addressing students' specific talents, individuality, and motivation on the basis of feedback (skill prints); (ii) integrates **technology-related humanities, social sciences, and economic sciences** into the core elements of the subject; (iii) is supported in its change policy by **strategic political decisions**. These three main theses are to be supplemented by the thesis that **future technologies**[60] ("Emerging Fields") must find their way into engineering education at an early stage to ignite inspiration for the resulting innovations. Depending on the results achieved, the extended scope of action may also be transferred to the natural and life sciences in the medium term.

Goals, measures. Establishment of diversified graduate cohorts through the talent-, interest-, and ability-guided opening of the subject-specific education • promotion of capacity for transdisciplinary cooperation and competence in design methods ("Design Thinking") • integration of life long learning into strategy for teaching and individual continuous learning • ongoing feedback to teachers and students.

■ **Student selection.** Suitability for study is based on the requirements of the so-called *qualified interdisciplinarity* with guided self-assessment (Skill Print 1.0).

■ **Adaptive learning.** The elements of individualized education are designed in such a way that they can be integrated into existing study programs. The organizational principle (Table 11) ensures the technical depth with respect to interdisciplinarity, connects it continuously with humanities, social sciences, and economics, and is suitable for life long education and training. As digital teaching and assessment formats (blended learning, inverted classroom) will play a key role in future academic education (WR 2017), both TUM EdTech (p. 40) and the TUM Institute for Data Science (p. 48) become instrumental in providing the respective expertises, together with the "Instructional Designers" and the planned faculty for digital education (Ref. 61c, p. 45).

■ **Bachelor of Engineering Science 2.0.** In a reformed 2.0 phase, the booming MSE program *Engineering Science* (BSc, 2010), which is compatible with many follow-up MSc programs, implements the new training principles as a pilot project, to transfer them consecutively to the natural sciences (*BSc Natural Sciences*).

■ **Process control.** *(a)* ***Interface Analysis.*** Synchronization of the module descriptions (terminology/metrics) in a generally accessible AI-supported database to highlight

| [59] **MIT study 2018** on the future of engineering education (Ruth Graham: The Global State of the Art in Engineering Education; Cambridge/USA, 2018).

| [60] **Examples:** Biomaterials and bio-inspired design concepts for engineering products • AI and autonomous systems, e. g., in construction robotics and medical assistance robotics • Edge/immersive computing.

university-wide cross-references between study offers and make them usable for interested parties in individual teaching packages (including for continuing education). – *(b)* ***Learning Analytics.*** Monitoring of individual competence acquisition and learning behavior: self-assessment of study progress, performance comparison with fellow students, sharpening of awareness of weaknesses and strengths through continuous feedback beyond exams (Skill Print 2.x), anonymized observation in the subject-area cohort. – **Requested resources:** 50 % of the required total funding (0.9 M€) for full-coverage Onboarding Weeks: 450 K€ p.a.; professorships, including "Learning Analytics": TUM budget. For all measures 10 M€ have been allotted for 5 years from central university funds.

Table 11: Organizing Principle for Adaptive Learning

(1) **Onboarding Week.** "Socialization" in the chosen field of study, highlighting current challenges of the discipline and their transdisciplinary cross-references (possibilities, limitations, new horizons). – (2) **Talent-oriented Branching of the Study Paths.** Update of guided self-assessment (Skill Print 2.0): *"Bachelor Plus"* for students with a delayed start or *"Bachelor/Master with Honors"* for ambitious, high-performing students with notable prior knowledge (+ 30 credits each; top 10–20 % cohort)[a). – (3) **Skill Profiling:** Structured AI- and counseling-based mentoring for the individual control of studies/further education along the "TUM Professional Profiles" (p. 53); Synopsis of personal competence acquisition. – (4) **Project Weeks:** Semester-wise one-week project phases to prepare for new transdisciplinary forms of teaching and learning, mainly with reference to humanities and social sciences (25 credits in BSc studies, corresponding to 15 % of study scope, of which 2/3 is blended learning for preparation/follow-up). – (5) **Plug-In Modules** (certificate formats, 10 credits) integrate new technologies that have thus far made only a rudimentary appearance in engineering studies[b)] as well as transdisciplinary system thinking[c)] (essentially blended learning for the creation of free spaces in study design). The partly digitally generated modules are also offered within "TUM.The Open University Initiative" (p. 38), which establishes the contact with students/alumni at an early stage through common attendance phases.

| [a)] Extended foundations and transdisciplinary projects/module in BSc, interdisciplinary engagement in TUM or participation in research projects in MSc. These students receive priority grants for the Deutschlandstipendium and membership in TUM:*Junge Akademie* (Ref. 42). – [b)] **Examples:** Artificial Intelligence • Additive Manufacturing • Robotics/autonomous Systems • Data Science • BioEngineering • Biomaterials. – [c)] **Examples:** Design Thinking and Creative Confidence • Risk Assessment and Risk Steering • Data-driven Protection and Services • Normative and Psychological Limitations in Technology Implementation • Communication Effectiveness.

A.3.2.2.3. School of Humanities, Social Sciences & Education

For the newly defined "German Engineering," the humanities and social and behavioral sciences (currently ca. 10 % of the faculty, Table 12, p. 45) gain a new context within the overall strategy: The gradual expansion to 84 professorships (2026; + 68 %) will deliberately change the metrics of TUM, to enable these research domains to develop their own profile in the field while at the same time creating sufficient integrative combining power and educational capacity for the mutual benefit of the natural and technical sciences[61] (p. 43). The **School of Humanities, Social Sciences & Education** (A.3.2.5.1.2) carries TUM's new approach to educational and research policy flanked by the MCTS.

Tab. 12: Humanities, social science, and behavioral science professorships at TUM

	Appointed professors		Visiting professors	
	Status (2018)	Target (2026)	Status (2018)	Target (2026)
Humanities	9	18	5	> 15
Social and behavioral sciences	41 (+ 8)[a)]	66	18	> 30

| a) *Ongoing appointments (8), effective 2019:* Digital Governance • Comparative Political Economy • Global Security & Technology • Global Health • Health Psychology • Health Sociology • Digital Health • Healthy Ageing & Physical Activity.

Measures. Doubling of the ***humanities faculty***[61a] responds to the rapidly growing need for knowledge, understanding, and explanation of the technical sciences, which are put into their societal context by the ***social and behavioral sciences*** (including political science)[61b] and ***educational sciences.***[61c] With this, the School will be in line with TUM's overall strategy to shape a technology-adaptive portfolio contrasting and meaningfully complementing what is available in the Greater Munich science community.

Requested resources: 3 professorships (open rank) in humanities/social sciences with 1.75 scientists each and expenses/investment 50 K€ p. a., 1 administrative position.

A.3.2.2.4. Munich Center for Technology in Society (MCTS 2.0)

With the MUNICH CENTER FOR TECHNOLOGY IN SOCIETY (MCTS, ExIni II/2012; A.2.2.1.2)[30], after the expansion around political science (2014/16)[62], the preconditions were in place for the future School of Humanities, Social Sciences & Education (A.3.2.5.1.2), in which the educational and pedagogical sciences are to be integrated within the framework of STEM teacher training (EDU Dept., 2009). This far-reaching reform approach aims to make TUM fit for *"Responsible Research and Innovation" (RRI)*[63], which brings a third dimension to technical excellence and entrepreneurship. To

| 61 **Planned new joint-appointment professorships** in line with the overall strategy **(a):** Law of Digitalization • Modelling in Science and Engineering • Philosophy of Mind & Cognition (Neurophilosophy) • Ethics in Data Analytics, Systems Design & Machine Learning • Intercultural Communication • Digital Literacy • Emotions of Politics & Technology. **– (b):** Social Studies in Robotics • Mobility Studies & STS • Security Studies & STS • Sustainability Studies & STS • Gender & Diversity in Engineering • Artificial Intelligence & Society • Qualitative and Quantitative Measures • European Integration & Technological Transformations • Global Trade & Innovative Technologies • Accountability in Politics and Technology • Energy and Climate Change • Sustainable Development in Africa • Politics in Urban Mobility. – **(c):** Engineering Education • Instructional Design in Science & Engineering • Learning Analytics • Cognitive Psychology.

| 62 Hochschule für Politik München (HfP, 2014) – TUM School of Governance (GOV, 2016). – Partnered with the **WORLD ECONOMIC FORUM** in **The Munich Politics Network**, and **Munich Security Conference**.

| 63 **Rome Declaration (2014) of the EU Commission:** "RRI is the ongoing process of aligning research and innovation to the values, needs, and expectations of society." – See EU H2020 Framework Program.

this end, the MCTS will be expanded in its transdepartmental function as an *Integrative Research Center*, following the successful joint-appointment principle, so that it can perform its extended tasks throughout the university (MCTS 2.0)[61].

Measures. ***(a) MCTS Independent Research Groups (IRGs).*** This new program pursues the *dual qualification of junior staff* in the humanities/social sciences and natural/engineering sciences ("convergence model"). There is an urgent demand for this internationally. The IRGs bring together basic competences in subjects from the natural, technical, and medical sciences *and* from the humanities/social sciences. Through its programmatic lead, the MCTS is pushing ahead the RRI. Annually 2 IRGs (3 years each, with renewal options, peer reviewed), start shortly after PhD in connection with TUM.Global Postdoc (p. 35). – ***(b) MCTS Research & Innovation Fund.*** To anchor RRI activities in *all* research networks (CRCs/TRRs, SPPs, Cluster initiatives) in the future, the participating humanities and social sciences faculty will be provided with project-related funds (ExStra) and personnel resources (TUM). – ***(c) Embedded Innovation Partnerships.*** To enrich innovation requirements through the humanities and social sciences or participatory approaches, TUM is opening an MCTS-led RRI process model to industry and politics. – ***(d) Teaching.*** Compulsory RRI teaching components in *all* study programs: **BSc studies:** Basic RRI training; MCTS and HfP/GOV provide course modules (e.g., Responsible Innovation). – **MSc-studies:** "Engineering for Society" certificate program (≥ 4 courses and Capstone Project; plug-in-modules). The MCTS Elite Master "Responsibility in Science, Engineering, and Technology" (RESET) will also become available for continuing academic education in the IL[3] (p. 39). – **Doctoral programs**: RRI Integration, mainly workshop formats (TUM Graduate School). – ***(e) Dialogue***. MCTS, HfP/GOV, and TUM-IAS are instrumental in promoting the exchange of knowledge between disciplines in the Project Weeks of the technical study courses (Table 11). The resulting best practice serves to iteratively increase the quality of training. – **Requested resources:** (a) 2 IRGs: 2 junior research group leaders + 2x3 postdocs, + 1 administrator/assistant, material expenses 100 K€ p. a. – (b) R&I Fund: 150 K€ p. a. – (e) 2 coordinators + 1 assistant (MCTS, GOV, TUM-IAS).

A.3.2.2.5. Expected effects

Human-Centered Engineering and Future Design, as a far reaching reform concept, aims to guide the technical excellence of "German Engineering" into modern society's worlds of thought. Heavy extension and full integration of technology-related **human, social and behavioral sciences** anticipates cross-cultural interdisciplinary fertilization of the traditional yet radically changing technical sciences in teaching and research. Thus, the entire agenda – including the profile-forming and high-potential research areas (p. 17–22) – can experience a horizon-widening dynamization: unprecedented in TUM's history, novel to the German technical universities, beneficial to the collaborative ONE MUNICH Strategy (A.3.2.3.2) and TUM's international positioning (A.2.1.7).

A.3.2.3. Recalibration of scientific interactivity

As part of a ONE MUNICH strategy, the uniquely strong, diversified Munich science and business environment will be consistently geared toward using the interaction potential and thus incorporated into international alliances:

A.3.2.3.1. Regional strategic alliances cf. A.2.1.5, A.2.1.6.

A.3.2.3.2. ONE MUNICH Strategy Forum

A strategy-building process is initiated in which the leading science *and* business partners from the Munich Metropolitan Area participate in creating common future perspectives and room for action, that harnesses complementary competencies. In this, TUM can rely on its excellent network in the industrial environment. The **ONE MUNICH Strategy Forum**, as a new cross-institutional research format, is established to activate the identified future fields through interdisciplinary project teams (up to 10 PhD positions per team, tandem supervision). The pool of PhD positions is based on a contribution of 5 posts per partner (TUM, LMU, MPG, HMGU, FhG, industry partners). The Presidents of TUM and LMU coordinate the forum by turns. **– Requested resources:** 1 project manager, 1 assistant; material expenses 150 K€ p. a. (Incentive Fund).

A.3.2.3.3. International strategic alliances cf. A.2.1.7.

A.3.2.3.4. TUM Institute for Advanced Study (TUM-IAS)

Having arisen from the 2006 Institutional Strategy and internationally highly visible, this institute is today the most prominent excellence platform of TUM. It plays the role model for the *TUM Integrative Research Centers* (p. 16; Fig. 8 p. 52) and shapes the Rudolf Mößbauer TT program. An impressive record[64] – thanks to Directors P. Dewilde, G. Abstreiter, and E. Rank – has placed the TUM-IAS at the center of the university and defined the standards for internationalization at the highest level. Substantial lines of renewal in research come together here, flanked by interdisciplinary, internationally high-level dialogue. The regular involvement of faculty (Faculty Day, Wednesday Coffee Talks), industry (Fellowships, specialist symposia) and the interested public (Science Matinee) also fulfills the expectations for a creative "knowledge exchange hub." The work and reputation of the TUM-IAS embody the vitality of a top-class "scholarly community," with effects that radiate throughout the entire

| 64 **Balance sheet 2012–2018:** Total investment 49 M€ (ExIni II/II and TUM) plus building 10 M€ (BMW Group). • 157 Fellows (70 % from abroad; 24 % female: 50 % since 2017 due to so-called Tandem Call Procedure) • 1,170 publications • 60 completed doctorates (> 100 currently in progress) • 20 Rudolf Mößbauer TT professorships appointed from top international universities, including 9 German returnees • ca. 400 scientific/public events • initiative for several DFG CRCs/Excellence Clusters • preliminary structuring of new TUM Integrative Research Centers • industry grants for fellowship programs (e. g., Siemens 2.16 M€ 2019–2021) • EU Cofund (5.1 M€ 2011–2018).

university. The basic financing comes from central university funds on a permanent basis (4.0 M€ p. a.). – **New measures** emphasize the overall strategy:

TUM Postdoc Fellowships. From TUM.Global Postdoc (A.3.2.1.3), TUM-IAS Senior Fellows will receive 2-year Fellowships for postdoctoral researchers to enhance the effectiveness of the so-called Focus Groups, enabling them to build up international networks at an early career stage. **– Short-term TUM-IAS Research Fellowships** (1–2 months) to recruit Senior Fellows who previously had no affiliation with TUM (often from under-represented regions such as Latin America), to formalize the planned TUM-IAS cooperation. **– Requested resources:** 100 K€ p. a. for 10 Fellowships. – **TUM Albrecht Struppler Clinician Scientist Fellowships** for physicians of the TUM university hospital to offer them, as "clinician scientists" (TUM Junior Fellows, lecturers, and the like) 50 % freedom to open up independent research at interfaces with the natural and engineering sciences, equipped with PhD/postdoc positions. **– Requested resources:** 450 K€ for three 3-year Fellowships, each with 50 % senior physician compensation; 1 doctoral candidate (50 % co-financed by TUM Medicine), 15 K€ material expenses p. a. **– TUM Senior Excellence Faculty.** cf. p. 36. **– Anna Boyksen Fellowship.** cf. p. 37.

A.3.2.3.5. The Data-Enabled University: TUM Institute for Data Science

Breathtaking advances in data generation, data usage, and computing architectures[65] have initiated a paradigm shift in research in which theory and experiment, as the classical means of gaining insight, are converging. Established today as a discipline, *Computational Science & Engineering* at TUM yielded international, highly sought-after MSc programs at an early stage (1998). Newly established as a graduate students' platform is the *Munich School for Data Science @ Helmholtz, TUM & LMU* (2018).

Goals, measures. To exploit the enormous potential of the data sciences for all areas of science and technology with concomitant integration in various fields of application, a professional, centrally managed **data management** is being established based on TUM standards[66] – accessible to all scientists and indispensable for top-level research. Centrally located in the new GALILEO building (Garching), the **TUM Institute for Data Science** bundles high-level competences from *informatics* • *mathematics* • *statistics*[67]. In a "loop of knowledge", it networks them with real-life application areas that can be expected to produce transformative advances through the use of data sciences and computational power[65, 68]. It develops innovative algorithms and methods for the efficient

| 65 **Leibniz Supercomputing Center** Garching (SuperMUC: 26.7 Petaflops/sec, ranked #8 worldwide).

| 66 See Understanding of Quality (p. 16) • TUM Patent Policy (2010) • TUM Open Access Policy (2014).

| 67 Analytics • Big Data • Cloud Computing • Data Mining • Machine Learning • Modelling • Optimization • Simulation • Visualization.

| 68 **Examples**: Additive Manufacturing • Precision Medicine • Smart Cities • Machine Intelligence • Astrophysics • Microbiome.

acquisition, evaluation, interpretation, visualization, and reuse of data. Competent partners[69] are integrated to support data-intensive activities in research and teaching (Cluster of Excellence, CRCs/TRRs, EdTech Lab)[70]. The institute is a typical example of "Higher Learning & Academic Services" (A.3.2.5.1.2), in that it opens up a sprawling topic, one that is highly challenging scientifically, in terms of methodology, applications, and curriculum (particularly for blended learning, p. 40/42ff.). It integrates the existing TUM Data Innovation Lab (M. Fornasier).

Organization: *Steering Board (3)*: CIO, M. Fornasier (MA), D. Cremers (IN). – *Executive Board (6)*: 2 professorships for Data Science, 1 member each from EXCs, LRZ, library, IT center. – **Requested resources:** 2 TT professorships (TUM budget), 1 executive office managing director, 3 postdocs, investment/expense funds 130 K€ p. a., TUM Data Science Grants (6 per year at 25 K€); set-up phase (2019 – 2021): + 590 K€ investments (infrastructure e. g., server), + 200 K€ expenses, + 1 sci. staff.

A.3.2.3.6. The Design-Enabled University: TUM Institute for Technology Design

In the concept of *"Human-Centered Engineering and Future Design"* (A.3.2.2.1), design thinking takes on a new dimension. Just as "Industrial Design" (F. Frenkler, since 2006) carried the holistic, perception-guided approach to architecture into the engineering disciplines in many different ways[71], so, too, has TUM, in the 150th year of its existence, seized upon the founding motto *"Scientiis et Artibus"* and is making it, in a modern interpretation, a cultural imperative: design as an essential, continuous companion to engineering research and education, in constant feedback with the new technical design spaces. Advanced technologies (such as additive manufacturing, p. 21) are thus opening up new, value-adding effects of scientifically anchored design on processes and products across the entire breadth of engineering.

| [69] TUM Information Center for Research Data Management • TUM IT Service Center • Leibniz Supercomputing Center (LRZ) • Research and Technology Transfer (TUM ForTe) • BMBF Project: DIFUTURE: Data Integration for Future Medicine • Munich School of Robotics and Machine Intelligence (MSRM) • Munich Center for Machine Learning (MCML) • Munich School for Data Science @ Helmholtz, TUM & LMU.

| [70] **Further objectives and tasks:** Computer-aided, integrated knowledge extraction for "predictive sciences" with reliable quantitative predictions • Advanced training programs on data science for scientists (Summer/Winter Schools) • Development of best standards for data management • Sensitization/training on Open Science (TUM IL^3, p. 39) • Expansion of TUM data repository and research data infrastructure • Translation of data-driven innovations in business, politics, and society through new visualization technologies.

| [71] **Examples:** Interdisciplinary conception and technical realization of the electric vehicles MUTE, EVA Singapore, and aCar Africa (2010–2018) • TUM start-up NavVis mapping trolley (2013).

Goal, measures. As a new *Integrative Research Center*, covering all TUM disciplines (Fig. 8 p. 52) the **TUM Institute for Technology Design** follows a great German tradition (Bauhaus, Werkbund) and incorporates a leitmotif of the overall strategy: connecting not only *subjects* but also their *cultures* in mutual fertilization. Competences from the engineering, computing, and economic sciences, and from architecture and industrial design, are bundled and applied to "real-world challenges." – *Partners:* Dyson School of Design Engineering (IC London); Design Academy Eindhoven; Singapore University of Technology and Design; Stanford Institute of Design; SUGAR Network (Stanford University Garage) as internationalization model, participation by KNUST (cf. TUM.Africa, p. 51); industry (Oerlikon, GE, Siemens).

Program components: *MSc program* "Technology Design." – *New professorships* (priorities up to 2025): Human-Centered Design • Design Methodologies • Industrial Design • Digital Fabrication Design • Building Product Design • Design-based Business Development. See also A.3.2.2.2 and A.3.2.2.4. – **Requested resources:** 2 professorships (open rank), 1 coordinator, 4 scientific staff, 1 assistant; set-up phase (2019 – 2021): + 600 K€ investments (infrastructure e. g., 3D printers), + 2 sci. staff.

A.3.2.3.7. Expected effects

Highlighted by TUM-IAS and supported by TUM's international alliances, the **recalibration of scientific interactivity** promises the massive advancement of existing and new top-level research in the Munich Metropolitan Area. The vision of Human-Centered Engineering and Future Design (A.3.2.2) receives cross-departmental support from the new institutes for **Technology Design** and **Data Science** (A.3.2.3.5/6). From the latter, competitive advantages to the young "digital era generation" are expected when it comes to handling Big Data, a paramount success factor in any future profession.

A.3.2.4. International presence: TUM.Global

Following the strong focus on developments in Asia (2000–2017), TUM is increasingly turning to *Europe*, and now also to *Africa*.

A.3.2.4.1. TUM.Europe

Goal, measures. The "European Flagship Partnership" with Imperial College London (ICL) deliberately counters "Brexit" with the development of relationships with an excellence partner, cf. p. 11. The TUM "White City Campus" branch in London, to be set up in the near term (2020), will be expanded in the medium term following the example of TUM.Asia (Singapore) to become a legally independent **TUM.London** in alliance with ICL (target 2026), in order to place international education, entrepreneurship, and research programs in one of Europe's most vital metropolises.

A.3.2.4.2. TUM.Africa

For a technical university of high standing, the African continent is a cultural-political desideratum (*"Engineering for Africa"*). TUM.Africa was initiated by the recently appointed top architect Francis Kéré (born in Burkina-Faso)[4] and the TUM Emeriti of Excellence (Kickoff symposium *"Sustainable Future for Africa"* 2018).

Goal, measures. Culturally coordinated teaching, research, and entrepreneurship platform with the KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY (KNUST) in Ghana, with the involvement of local and German stakeholders (universities, schools, NGOs, business), cf. German "Marshall Plan for Africa" (BMZ). Interdisciplinary projects focusing on water, food, energy, urban development, global health, and mobility • integration of the EXC *"Africa Multiple"* (University of Bayreuth) and social sciences[61b] • use of digitalization technologies in the German-African cooperation (virtual platforms, best-practice exchange, networking) • international entrepreneurship. – **Requested resources:** Fundraising Coordinator (TUM.Africa), Project Coordinator (TUM.Europe), 1 team assistant; seed fund for cooperation projects 250 K€ p. a.; set-up phase (2019–2021): + 500 K€ travel costs for initiation of projects.

A.3.2.4.3. Expected effects

TUM.Global adds new emphases to TUM's extensive, far-reaching international experience. The association with ICL creates an exemplary strategic partnership of excellence in Europe. **TUM.London** anticipates the development of powerful interaction potentials in the British science and business metropolis, combined with the idea of European Unity. **TUM.Africa** should boost the awareness, within the academic community of a technical university, of responsibility for the development needs of the African continent. The Bayreuth Cluster of Excellence "***Africa Multiple***," to which TUM brings the technological dimension, promises a mutual activation of potential.

A.3.2.5. Future-proofing university governance and administration

A.3.2.5.1. Reorganization of the university

The reform successes of TUM, combined with the constantly expanding international radius of action, have revealed the limitations of the traditional organizational structure. Department-specific teaching and research programs do not keep pace with the necessary development of system competences. As a means of counterbalance, TUM has repeatedly created innovation areas with cross-cutting effects by means of *Corporate Research Centers* and *Integrative Research Centers*[72]. Nevertheless, the

| [72] **Examples**: Research Neutron Source FRM-I (1960) • Walter Schottky Institute for Semiconductor Physics (1986) • TUM Institute for Advanced Study (2005) • Munich School of Engineering (2010): Focusing on energy research and leadership in the "Engineering Science" reform study program (BSc) – 204 new enrollments out of 354 applications (2018).

(additively) grown organizational structure – 15 departments, 28 organizational units – has proven to be insufficiently interactive to proactively pick up new fields of innovation These inherent systemic drawbacks should now be overcome structurally, cf. WR 2018.

A.3.2.5.1.1. Matrix structure

A top-class university uses disciplinary depth for interdisciplinary interconnections. Consequently, the TUM AGENDA 2030 steers toward a *matrix organization* based on international models in a transformation process with gradual adjustment of internal structures (Fig. 8) in order to activate dormant interaction potentials in larger units (Schools), thus resulting in system-integrative networks (see profile forming and high-potential research areas, A.2.2.1.1/2, p. 17–22).

A.3.2.5.1.2. Schools with departments

The **TUM Schools (A)** form the basic structure. They describe the major scientific domains and structure the overall portfolio through departments. In the first step of the transformation, existing departments will be incorporated into the Schools, where they serve the field-related scientific identity formation and calibration within the respective scientific communities (international benchmarks). To activate synergies, relevant professorships are reassigned within TUM.

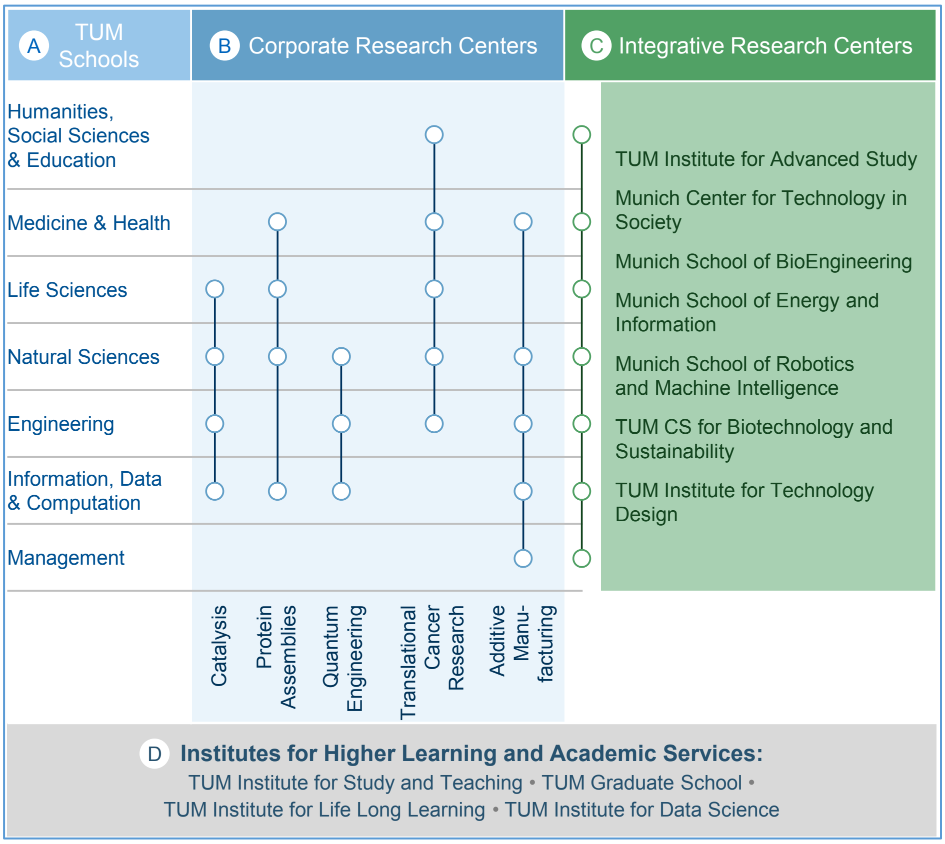

Fig. 8: The new matrix structure of TUM. The *Integrative Research Centers* activate the pertinent competence domains of *all* Schools.

Through the ***TUM Professional Profiles***, the Schools control the new and further development of study programs, that flexibly meet the changing needs of global labor markets. Through the ***TUM Innovation Networks*** they control system-wide research approaches/technologies across departmental borders. Beyond conventional subject identities, the Schools activate interaction potentials and thus extend established effectiveness radii by forming "bottom-up" competitive focus areas and overarching centers: **Corporate Research Centers (B) • Integrative Research Centers (C) • Institutes for Higher Learning and Academic Services (D)**, Fig. 8.

A.3.2.5.1.3. Strengthening of interdisciplinary research

Based on the sustained strengthening of research across departmental boundaries and the further development of the curricula, the following formats serve to accelerate the transformation of TUM from a subject-oriented to a *system-oriented top university:*

(a) TUM Technology Core Facilities are technically equipped central units that, with support from Technical Experts (CareerDesign@TUM, A.3.2.1.2), provide scientists with state-of-the-art technologies and complex scientific services for research projects and clinical studies. Under construction: *TUM Electron Microscopy Core Facility, TUM Mößbauer Technology Center.*

(b) TUM Innovation Networks. Systematic development of innovation focal points with which new connectivities between Schools/Departments can be tested as a basis for future fields of innovation[73]. As "scientific speedboats" in strategic research fields ("Emerging Field Policy"), they promote the international visibility of the "TUM brand". **– Requested resources:** 2 Networks p.a. with 7 doctoral candidates each (3-year duration) + 75 K€ material expenses per Network/year.

(c) TUM Corporate Research Centers are organizational formats that have proven themselves many times in generating a critical mass of competence in special areas of research (e.g., catalysis, semiconductor, nutrition, and cancer research). They perform basic and applied research, mostly in cooperation with non-university research institutions and industry. In the future, they will no longer be created "top down" but rather through successful *TUM Innovation Networks* (b).

(d) TUM Integrative Research Centers (IRCs), p. 16, are interconnection formats characterized by interdisciplinary research programs in which scientists from several Schools collaborate on a long-term basis with Munich-based and international top-level researchers (e.g., TUM-IAS Fellows), mainly in TUM's profile forming research areas (A.2.2.1.1).

A.3.2.5.1.4. Strengthening of cross-system teaching: TUM Professional Profiles

Professors in the relevant subjects work with experts from the field to design *competence profiles for future professional careers*. Cross-cutting fields (new technologies; humanities /

| [73] **Examples:** Fluid Functional Materials • Risk Analysis • Biomaterials.

political, social, economic sciences) are integrated. The *TUM Professional Profiles*[74,75] will thus grow far beyond the discipline-based study structures typically found at German universities, cf. A.3.2.2.1/2.

A.3.2.5.1.5. Tasks, responsibilities

Schools. Based on the principle of subsidiarity, the new governance thrives on the strengthening of science. Consequently, some of the new departmental tasks are transferred to the largely autonomous Schools (with full-time Deans) and some to the departments (with part-time Chairs). – *Responsibilities:* sovereignty over personnel/resources • conception of competence profiles (disciplinary/interdisciplinary/study programs) • joint research programs and research infrastructures (TUM Technology Core Facilities) • implementation of joint funding programs for junior researchers (Graduate Centers). – To lend vitality to new synergies and relieve the burden on departments, the Schools also take on higher-level strategy responsibilities: **research** (interdisciplinary research alliances, project management) • **teaching** (study concepts, student counseling, examination issues, course/quality management) • **technology transfer/entrepreneurship** (e.g., scouting) • **administration** (e.g., human resources, procurement, controlling, IT support).

Deans. They are *ex officio* members (6-year term of office) of the Extended Board of Management (General Presidium)[76], the university's strategic steering committee. In light of their wide-ranging responsibilities, they decide on the use of personnel, expense, and capital resources. An *Innovation Fund* allows for developmental control over the incorporated departments to the benefit of their mutual relationships, synergies, additions, and adjustments.

The **teaching structure** is organizationally divided into three parts: (a) TUM Institute for Study & Teaching (for BSc/MSc studies) • (b) TUM Graduate School (for PhD phase) • (c) TUM Institute for Life Long Learning (for continuing education, A.3.2.1.8). The responsible Senior Vice Presidents chair the steering committees (Councils).

A.3.2.5.1.6. Implementation

In line with academic convention the operational design is entrusted to the subsidiarity principle. The full implementation of the governance structure is targeted for 2025, and consolidation with necessary adjustments for 2030 (TUM AGENDA 2030). The audit-based change management is headed by the President, supported by a panel of experts. All

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| 74 **Examples:** Environmental Engineering • Material Sciences • Computational Engineering • Mechatronic Engineering • Data Science.

| 75 Each competence profile represented in a degree program is assigned to a *TUM Professional Profile*. The establishment of the Professional Profile takes place centrally at the suggestion of the School, with involvement of the Teaching Board/Teaching Assembly. In this way cross-departmental synergies are utilized, narrow concentration of a department's course offerings that could be harmful to the competence profile is avoided, and the professional world is fertilized at an early stage by innovative technologies.

| 76 **Responsibilities**: University development planning, research priorities, multidisciplinary research centers, teaching strategy.

important decisions are made by the Board of Management, taking into consideration the recommendations of the panel of experts and the ***Reform Senate TUM2030*** [77], cf. A.3.4.

A.3.2.5.2. Reorganization of Medicine

The Department of Medicine[78] is linked by staff union (faculty) with the TUM University Hospital and the German Heart Center Munich. Despite its excellent clinical and scientific achievements, it has not fulfilled the founding mandate (1967) to tap into the technology portfolio of TUM. To give scientific and clinical success equal space in rapidly advancing fields of research, Medicine is being given a new, innovation-promoting **matrix structure of clinics vs. research centers** (Fig. 9) imbedded in the overall governance structure (A.3.2.5.1). **Sections** within the clinics should support the development of clinical programs. The **Research Centers** are defined thematically as scientific questions change (clinical-translational, basic, organ- or function-related, or technological-methodological approaches). In this way, the traditional subject areas get broken up by the formation of interdisciplinary focus areas. **Guiding strategy:** *prevention • early diagnosis of disease • precision medicine*, see p. 21f.

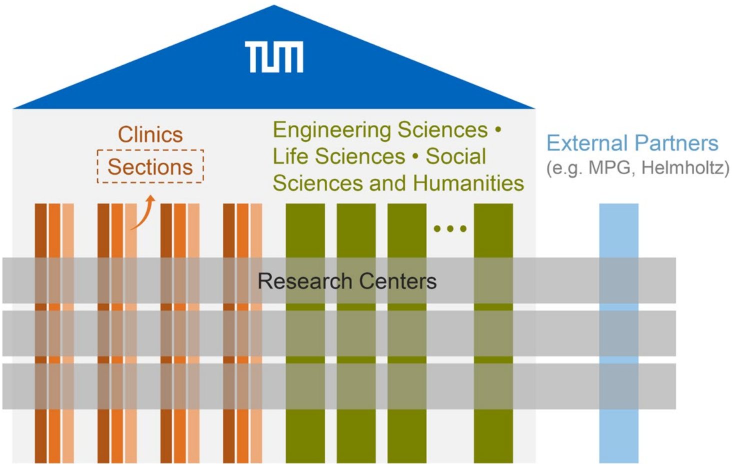

Fig. 9: Matrix structure of clinical medicine: Clinics (with sections) and Research Centers.

The matrix structure with Research Centers (modeled on TranslaTUM, 2017) is best suited to confront the technology desiderata of the medicine of tomorrow with profile-shaping emphases, particularly by coupling the life sciences and the natural/engineering sciences into a holistically defined medicine. This interdisciplinary interlacing is sustainably strengthened through **joint appointments**. Some new, interwoven topics of the centers have already been created[79]. Personnel strategy is based on the promotion of young **A. Struppler Clinician Scientists**, with a focus on their scientifically independent career development (TUM Faculty Tenure Track) and capacity for interdisciplinary interaction (cf. TUM-IAS, p. 47). They are expected to make significant contributions to the dynamization of basic research in the clinical environment.

| [77] Staffed by 12 internal/external experts from administration and science. – The *Reform Senate TUM2030* controls the implementation of all structural measures of the overall strategy (A.3.4).

| [78] **Largest department of TUM** based on number of professors: 90 faculty members, 1,810 scientists, 2,100 total staff (excl. nursing staff), 1,161 beds, 60 M€ third-party research funding (2017). – **German Heart Center Munich**: Clinic of the Free State of Bavaria at TUM.

| [79] Genomic Medicine, Digital Health & Medical Informatics • Intelligent Medical Assistance Systems & Medical Robotics / Geriatronics • Biomedical Imaging. – **Basic projects**: DiFuture (BMBF) • MSRM incl. Geriatronics • 1000 Clinical Genomes for Rare Diseases (GENOMBAYERN).

Organization. Full-time management spokesperson of a medium-term consolidated department/clinic structure (staff union Dean/Medical Director; law amendment necessary). – Research Centers: 5-year term with renewal option, external/internal steering committee, peer review-based quality management. – **Requested resources:** A. Struppler Fellowship (cf. TUM-IAS, p. 47); research fund 300 K€ p. a.

A.3.2.5.3. University administration: service-oriented, digital, international

Rapid growth, internationalization, new modes and structures of work, together with intensified competition for talent and money, make it difficult even for an efficient administration[80] to keep pace with the change dynamics of TUM. As a matter of consequence, the ***modernization of the administration*** is now becoming a ***central key objective in the overall strategy***.

Goals, measures. *"Customer-oriented" services* of the administration processes • *digital transformation* of work processes • *international conditioning* of administrative staff:

■ **Personnel.** The ongoing qualification of employees gains new significance: a) ***Onboarding***. Employees are trained in mandatory on-boarding/trainee programs for the new ways of working and the "TUM core values." – b) ***Internationalization***. Through the new *Maximilian Graf Montgelas*[81] *Fellowship Program*, administrative staff gain experience in foreign reference universities (e.g., ICL, Stanford, NTU Singapore), research institutions, or business enterprises. Vacant leadership positions are advertised internationally and are filled in such a way that external experience and intercultural competence in the administration take effect. The staff of the TUM Language Center is being increased (+ 6) to boost foreign language competence in the administration, under the *strategic goal of multilingualism*, and thus empower staff to deal with TUM's increasingly international audience. – c) ***Job rotation.*** University-wide as an element of further qualification and for the dissemination of best-practice standards.

■ **Processes.** Universal digitalization of administrative processes, networking, and breaking up of "silo structures:" a) ***Omnipresence and "Online First" Strategy***. Personalized access to multilingual TUM data/documents and use of TUM services regardless of location and at any time. – b) ***Seamless digital business processes and campus management***. IT/Cloud-supported and user-centered processes (user-

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| 80 **Number of employees 2017**: 1,586, of which 846 decentralized administration. – **Examples of initiatives implemented early on:** Introduction of SAP R/3 (2002) • Performance-/load-indexed resource disposition for the departments (1998) • TUM Chief Information Officer (Senior Vice President, from 2001) • "Vision TUM2020" structural project (ExIni II) • Interwoven central/decentralized administrative structure (since 2000) • University-centralized Student Service Center (2003) • Global Budget (2007) • Central control of technology transfer and IP security (TUM ForTe, 2009) • Library reform (1999) • Restructuring program *Innova*TUM (reallocation of 420 staff positions in favor of priority areas; 2004–2008).

| 81 Bavarian Reform Minister 1799 – 1817, creator of the modern state administration.

experience design), possibility for online certification/signatures, electronic ticket system for seamless accessibility and individualized feedback for all administrative processes, blockchain piloting for academic degree documents in collaboration with international partner universities. – c) ***Digital Employee and Alumni Life Cycle***. Holistic recording/documentation of the entire qualification and feedback cycle of employees/alumni in a systematic embodiment of modern talent management.

■ **Structures**. The new tasks require an administrative reform (TUM2030) that, among other things, also successfully implements the new governance (A.3.2.5.1): *a)* ***Vice President for Digital Transformation.*** Design and implementation of digital processes in common mode for all TUM facilities (regardless of location). – *b)* ***Interactive controlling.*** Prospective control and ongoing reconciliation of financial, personnel, and property planning. – *c)* ***Reform Senate TUM2030.*** Accompanying and steering committee[77], also responsible for the external peer review processes every two years.

Requested resources: Mobility fund 0.9 M€ p. a. (personnel increase to compensate for deficits in work processes resulting from vacancies due to training, Language Center; funds for Montgelas Fellowship); training fund 300 K€ p. a.; set-up phase (2019 – 2021): + 2 IT technicians to implement the digitalization strategy; digital administration expense/investment funds (e. g., staff training, programming/development, licenses) up to 2 M€ p. a. (TUM budget).

A.3.2.5.4. Science communication, University marketing

Motivation, measures. The "TUM brand" is bound to values (mission statement). Given the boisterous, multidirectional expansion as well as the intensified international competition for top talent, the brand and its values need to be conveyed, explained, and defended. While the media work of the TUM Corporate Communications Center (CCC) collects and processes countless individual pieces of information (print, audio/video, web, social media)[82], the task of an academically committed marketing strategy lies in elaborating/accentuating those essential elements that make up a value-based overall strategy. Understood in this way, **university marketing** is the actively shaping messaging platform for what is crucial to the university: effectively reaching student applicants and interested parties in Germany and abroad, schools, partner institutions, media, politics, society, donors, businesses, and industry. New in the German higher education landscape, this requires a principled, strict, centrally controlled marketing strategy (Vice President for *Communications & University Marketing*). – International **science communication** will be strengthened and perpetuated with a focus on social media and the international platform.

| [82] **Balance sheet 2016–2018 (TUM Corporate Communications Center):** 614 news releases • 2,565 TUM-related radio/TV stories • 69,350 mentions in print/online media (#1Ger.; ahead of LMU 60,496 and RWTH Aachen 55,723) • 11,929 online mentions in Americas/Asia-Pacific (+ 280 % *vs.* 2012) • Currently 85,500 Facebook "likes" (#1Ger., ahead of LMU), ca. 24,000 followers on Twitter (#2Ger., after LMU).

For this purpose, a science journalist with work experience abroad will be recruited to TUM. – **Requested resources**: *University Marketing:* Head – • – (TUM University Foundation); 2 sci. staff, 0.5 IT technician, material costs 150 K€ p. a. – *Science Communication/Media Work (CCC):* 1 sci. staff, 0.5 IT technician, 1 science journalist (120 K€ p. a.), material costs 100 K€ p. a.; restructuring phase (2019 – 2020): + 2 sci. staff (marketing), + 1 IT technician (to set-up media database); + 900 K€ expenses (external consulting, training).

A.3.2.5.5. Expected effects

Future-proofing of governance and administration aims to lend vitality to excellent research: The fundamental reorganization of TUM is expected to overcome old-fashioned boundaries between disciplines, thus liberating untapped research potentials. In a pilot function, the novel matrix structure of Medicine helps to dynamize the German hospital structures by resolving subject-restricted compartmentation. A modernized administration that meets international standards advances excellence in research, while at the same time ensuring “customer satisfaction”, relieving professors and scientific staff of administrative ballast, and providing for individualized, diversity-equitable career promotion. A science-adaptive university marketing enhances the communicative valorization of the public and fosters the corporate identity (“proud of TUM”; Public Awareness of Science).

A.3.2.6. TUM AGENDA 2030: Overall significance for the university and for the German higher education system

The overall strategy builds on the growth and reform era of two decades, which with the help of the Excellence Initiatives has mobilized all dimensions of performance and made TUM prominently visible worldwide (A.2). Like the previous reforms of university governance (1998) and the appointment system (“genuine Faculty Tenure Track,” 2012), the following strategic and structural measures are expected to boost not only scientific excellence and to produce coherence effects in the academic community, but also, beyond that, to yield spill-over effects on the German higher education system in general:

CareerDesign@TUM: talent-promoting human resource development of the mid-level academic staff (A.3.2.1.2). | **Human-Centered Engineering and Future Design:** in-depth reform of the German engineering education (A.3.2.2.1/2). | **Humanities and social sciences** with technology-oriented profile: consistent expansion and compressive integration in teaching and research (A.3.2.2.3/4). | **Life long learning:** paradigm shift in the higher education system (A.3.2.1.8). | **University governance:** fundamental reorganization – including medicine – to promote fertilization of scientific interactivity across traditional disciplinary domains and cultures (A.3.2.5.1/2). | **University administration**: unprecedented reform campaign for internationalization and digitalization (A.3.2.5.3). – Borne from the spirit of **gender- and diversity-oriented talent promotion on all levels** (A.3.2.1), TUM AGENDA 2030 is expected to advance the university to the international top league, fostering high-level scientific interactivity by exploiting and expanding the strategic alliances as well as new scientific platforms with interdisciplinary impact (A.3.2.3.), with particular emphasis on **Technology Design** and **Data Science** (A.3.2.3.5/6).

A.3.3. Governance and management structures

Committed to the principle of subsidiarity, TUM's 1998 governance reform has proven its worth. The operational levels **Board of Management** and **Deans** were strengthened in a task-specific manner and cooperate institutionally in the **Extended Board of Management**[83] (C.7.2). Through the **Board of Trustees**, which consists of the Senate (10) and external members (10), the level of oversight and control has been considerably strengthened, ensuring a system of "checks and balances" aligned with the international model. The basis is the **Bavarian Higher Education Act**.

The **President** and **Senior Executive Vice President** ("Kanzler") are regularly available to staff through confidence-building platforms for the sharing of information, ideas, and criticism. **Students** are integrated into the teaching and study agenda through the *Academic Affairs Commission* and the *Parliamentary Council* – a special participatory feature of TUM (since 2009) – and in constant communication with the Senior Vice President for Academic and Student Affairs. The **spokespersons** of the **TUM Graduate Council** and the **scientific staff,** as well as the **women's representative**, are in the **Senate**. The **University Council** (Kuratorium, 25) performs a consulting function.

The **Extended Board of Management**[83] sets the framework for strategy development (including appointment and structural policy, research buildings, teaching constitution, agreement on targets), determines profile forming and high-potential areas of research (cf. A.2.2.1.1/2), and adopts priority programs of research (incl. DFG-CRCs/TRRs). Statutory authority and strategic decision-making (e. g., study/examination orders, creation of departments, Basic Order of TUM) is the responsibility of the **Senate** and **Board of Trustees** as legislative bodies. With its well developed, reform-tested culture of division of powers in shared responsibility, TUM is in optimal condition to execute this overall strategy.

A.3.4. Monitoring for quality assurance and success monitoring

The implementation of the overall strategy rests on stringent ***quality management***, tested in the major projects ExIni I/II (2006–2018; p. 29) and numerous other measures

| [83] *At present:* President, Senior Vice Presidents (5), Senior Executive Vice President (Kanzler), Deans (15), Spokesperson of Study Deans, Women's Representative; *non-voting*, Chair of TUM Emeriti of Excellence. – Vice Presidents for specific tasks (Basic Order of TUM §3 sentence 4), e. g., Controlling & Planning • International Faculty Recruitment and Career Programs; *in future also:* Compliance • Quality Management • Communications & University Marketing • Digital Transformation.

of the relevant performance dimensions (Fig. 3 and Fig. 4, p. 29). On the working level, the *Vice President for Quality Management*[83] (new) coordinates the process: In line with previous practice, the projects/measures are subject to ongoing monitoring by members of the Board of Management responsible for the respective portfolios, based on several ***TUM AGENDA 2030 Task Forces.*** The strategy monitoring takes into account the different time horizons; the structuring occurs over defined milestones (Fig. 10).

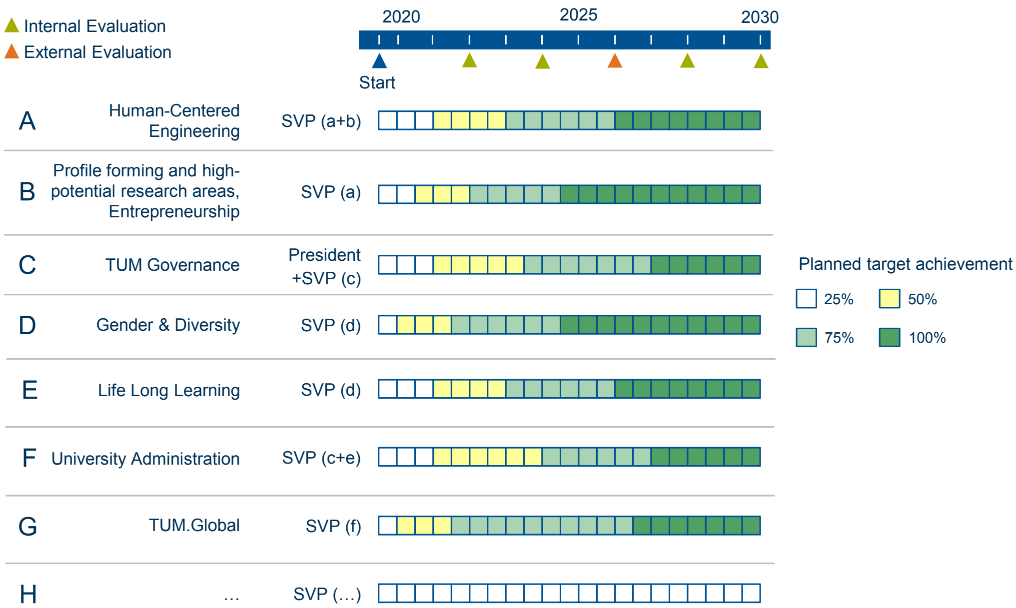

Fig. 10: TUM AGENDA 2030. Project management for selected programs of measures with schedule and responsibilities: - Senior Vice Presidents for (a) Research & Innovation, (b) Academic and Student Affairs, (c) Human Resources, Administration and Finance (Kanzler), (d) Talent Management and Diversity, (e) IT-Systems and Services (CIO), (f) International Alliances and Alumni.

Medium- and long-term developments with multiple interdependencies require quality-assurance monitoring far beyond the 2026 funding horizon. The verification of effectiveness and degree of achievement is carried out in regular evaluation phases according to (a) *quantitative* (KPIs) and (b) *qualitative* indicators[84]. After analysis of the results with the involvement of all stakeholders and the *Reform Senate TUM2030*, the Board of Management decides on necessary adjustments. To avoid conflicts of interest, project implementation responsibilities are decoupled from quality assurance. The ***Reform Senate TUM2030***[77], chaired by the President, is the coordinating oversight body for the overall process. If necessary for the purpose of redirection or termination of measures, the results will be submitted to the Board of Trustees for a decision. – **Requested Resources:** 2 project manager, 2 assistance, 10 K€ travel expenses Reform Senate TUM2030 p. a.; set-up phase (2019–2021): + 200 K€ expenses for external experts.

| 84 **Examples:** (a) Number of postdocs from abroad • share of female professors appointed • scientific awards and prizes • publications • third-party funding for teaching, research and promotion of young talent. – (b) Introduction of reformed study programs • implementation of reform steps and the new TUM Governance.