EU FP7 Project Light.Touch.Matters

Design driven, materials anchored:
How design input shaped the LTM materials stream

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1. Introduction

The materials stream in Project LTM aims to develop novel smart materials that allow "the product to become the interface". These "LTM materials" consist of four distinct technological components: piezo plastics for touch sensitivity, OLEDs for luminescent response, a conversion layer for modifying colour; and control electronics (i.e. flexible wiring, power supply, input-output switching IC). Moreover, the materials are being developed with design input, obtained through interaction with the design stream. So, Project LTM is a test case for design-driven materials innovation (DDMI).

With the project nearing its conclusion, the time has come to reflect on how this DDMI has in fact taken its course. In other words, to what extent has the materials RTD activity been "business-as-unusual"? This document contains such a reflection. It starts with what was expected in terms of design input for the materials stream (section 2), moves with an intermediate reflection (section 3), and then presents the evidence exhibited by the project (sections 4 and 5). Short conclusions round off this document.

A note on terminology is in place here. Project LTM highlights the fundamentally different outlook that product designers and material scientists have on the subject matter, with the former looking "outside-in" and the latter looking "inside-out". An OLED, for example, is considered to be a luminescent *material* by the designers, but is considered to be a *device* – itself consisting of several different materials and components – by the scientists. Also, while designers think mainly in terms of what materials mean to users, referring to subjective qualities (e.g. "sexy feel, warm light"), scientists think more objectively, referring to quantities. These differences in outlook, while not black-and-white, mean that seemingly ordinary words such as "properties" or even "materials" can have quite different meanings to both sides of the cooperation. This reflective document attempts to use the perspective of the material side of the project, with the resulting use of terminology.

2. Expected design input: the DoW

The "description of work", or DoW for short, defines Project LTM in the manner that is common for EU research projects. In its Part B, the DoW laid down performance targets for the LTM materials and described the expected design input. That text originated from the consortium's project proposal, which was drafted in November 2011, then expanded and updated in May 2012. As this text represents a logical starting point for this reflection, it is copied here in its essentials.

Development targets for the piezo plastics and OLEDs (including colour effects) were defined as presented in Tables 1 and 2 below. For the piezo plastic RTD work, concrete design input was expected to take the form of specifying the (precise) requirements for geometries, levels of touch sensitivity, and matrix materials. This work was to be performed as part of WP2. Note that as the piezo plastics were assumed to be fully covered by the OLEDs, no specific visual or tactile requirements for this touch-sensitive component were deemed necessary.

Table 1: Target properties of the piezo plastics	
Sensitivity	Sufficient to sense touch by fingers or hands
Size, thickness and weight	15 x 15 cm @ 0.1-0.2 cm, < 0.3 gram/cm^2 (unit size)
Matrix materials	Primarily polyurethanes and epoxies, plus possibly thermoplastic rubbers
Flexibility i.e. strain-to-failure	Minimum 1% (= sufficient to bend a 0.2 cm thick layer over a 10 cm radius)
Cost	Target cost price 1 euro/cm^2 (integral cost price)
Scalability of production	Suitable for medium- to high-volume production (100,000 products/year)
Lifespan and durability	3-10 years, depending on application and polymer used
Environmental properties	Best-in-class

For the OLED RTD work, concrete design input was anticipated regarding the desired shapes, sizes, and luminescent output colours. OLED grid patterning was identified as another variable to possible benefit from design input: the aim was to either make these patterns invisible or to make them according to specific graphic designs. Also, specific colour effects (e.g. gradients) were foreseen as a response to designer requests or suggestions. This work was to be performed as part of WP2 as well.

Table 2: Target properties of the OLED devices	
Colours	Bi-colour, (possibly) multi-colour, high brightness, various patterns and shapes
Light output	> 30 lumen/watt, with minimal visibility of silver grid on anode
Size and thickness	15 x 15 cm @ <0.1 cm total thickness (unit size)
Base material	Plastics: PET- or PEN-based
Flexibility	Sufficient to bend a 0.1 cm thick layer over a 10 cm radius
Cost	< 10 euro @ 15 x 15 cm
Scalability of production	Yes, to medium/high volumes (100,000 units/year)
Lifespan and durability	3-10 years, depending on application and light colour
Environmental impact	Best-in-class

Further expectations regarding design input were presented in Part B's section on progress in integration. To illustrate, a sketch of the LTM material "stack" was provided, which is reproduced in Figure 1 below.

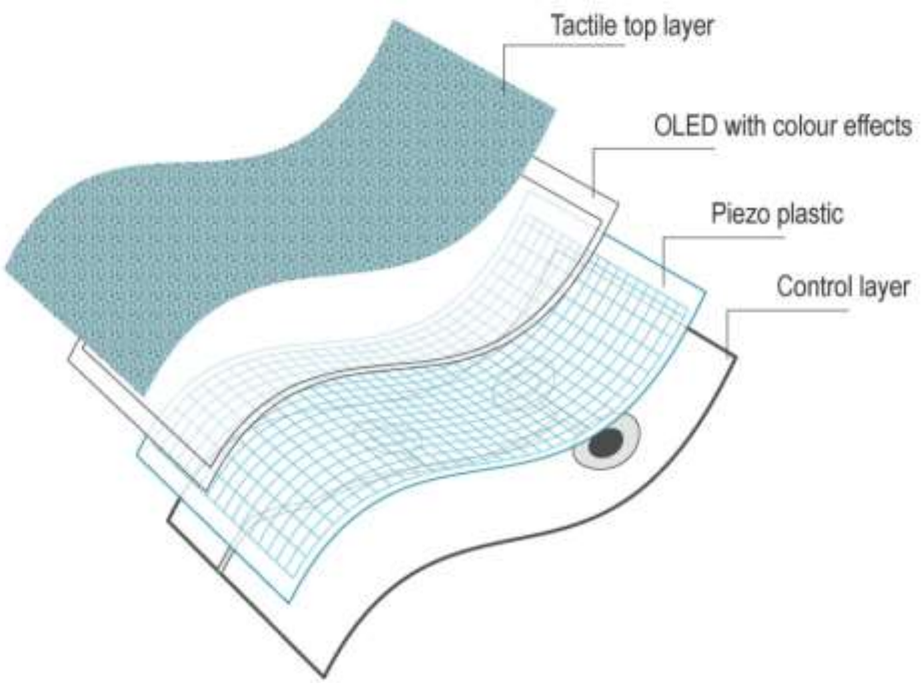

Figure 1: projected LTM material stack (Nov. 2011)

At that time it was already foreseen that the input-output functionality provided by the control layer could take numerous forms, with differing levels of complexity (from simple on-off switching to more advanced effects, and from there to functionalities in which the LTM materials are combined with other sensing and/or responding components). From an engineering point of view, the possibilities are almost limitless. Therefore, regarding integration, designers were first expected to help **identify the most promising input-output functionalities** to be developed.

Furthermore, specific design input was projected to occur in the development of:

1. "Development of **aesthetic and functional top layers** for the smart materials: in response to specific design requirements, we will develop flexible top surface layers offering unique tactile as well as visual features […];
2. **Integrating into products**: we will investigate how the smart materials can be integrated into- or onto specific products (with shape factors/curvature specified by the designers) using established manufacturing methods […]. All in all this is a sizable task, but one where the lateral thinking of the designers in the consortium, as well as our manufacturer's panel, are expected to be of great value;
3. Perform **upscaling studies**: […] we will study how manufacture can be scaled up to larger production volumes and brought down the (existing) production chains. Here the fit with more traditional manufacturing techniques such as injection moulding is key. Again, here lateral thinking by the Design SMEs […] will be of great value."

This integration-oriented work was projected to take place in WP4.

Alongside these expectations and targets, it is instructive to consider how the relative efforts of designers and scientists were to be spent, according to the DoW. Taken together, WP2 and WP4 – i.e. the materials stream – was planned to be 77 + 75.5 = 152.5 person-months, or PMs. This was 35% of the total projected PM budget for Project LTM. By comparison, the design stream, consisting of WP1 and WP3, was to take up 147 PM, or 34%. Zooming in, we see that in WP2, the actual design input was 12.5 of the 77 PM (16%, or 3% of total). In WP4, design input was expected to be stronger: 26.5 of the 75.5 PM (35%, or 6% of total). These data are repeated schematically in Figure 2.

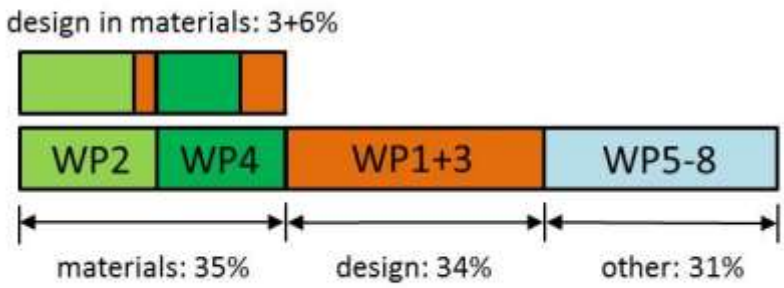

Figure 2: expected design input in materials stream, in % of project effort

For these figures, only the efforts by the eight design SMEs are considered. Of course, a certain concrete design effort is also provided by partners such as DUT-IDE, MCI and Brunel-HCDI, which means that these percentages are actually higher. We can conclude therefore that the DoW was written with substantial designer involvement in mind in the materials stream, particularly for the integration-oriented work in WP4. To this can be added that analysis of actual PMs spent in the project shows that these match the projections very well. So, at least in terms of effort by the people involved, the design input in the materials stream has been considerable also.

3. Intermediate reflection: the 2015 Design Management conference paper

In June 2015, the LTM project joined forces with its DDMI "sister project" Solar-Design in a presentation at the Design Management conference (Pisa, June 23-26th 2015). That paper[1] provides a preliminary reflection on how DDMI takes its course, first by listing the various ways in which designers can get involved in the development of new materials, according to literature[2]:

1. "by assisting in the **fabrication and development of models and prototypes**: the designer's skills in model making, prototyping, and computer-aided design (CAD), and their knowledge of materials and manufacturing processes can benefit scientists by allowing them to quickly evaluate ideas in reality, demonstrate the feasibility of concepts, and provide evidence to support funding applications;
2. bringing the **perspective of users and the marketplace** to research: the designer's focus on the needs, motivations, and behaviours of users and consideration of market requirements can speed up the process of commercialization and help to focus research objectives;
3. **communicating the potential of new technology** to investors and other non-scientific stakeholders: by visualizing "market ready" embodiments of potential future applications, industrial designers can help to communicate the key benefits of new technology in an engaging way that can be understood by a wider audience;
4. exploring and demonstrating **applications for new technology**: industrial designers can challenge what scientists believe the potential applications of their technology might be, and support the development of demonstrators. Designers are also able to embody the "unique selling points" of technology in applications;
5. identifying **routes to commercialization**: designers may be able to provide support for scientists struggling to gain investment in the development of new technology, by identifying new routes to market or lines of scientific enquiry;
6. providing **early insight into practical issues**: by attempting to make objects, industrial designers can help to identify the practical capabilities and limitation of new materials, and highlight any potential issues which may arise in scaling up new technologies (both in terms of physical size and volume);
7. **influencing the research direction**: by identifying practical challenges for technologies to overcome in order to achieve application, industrial designers can potentially influence the direction of research."

The same literature source goes on to note that "designers […] have a powerful role to play in supporting scientists in taking breakthrough ideas from the laboratory into commercial products. However, this important resource is often underutilized and the potential for design is frequently not recognized. It is rare for the scientist to involve such design expertise unless they have already progressed some way toward commercialization."

The conference paper continued by noting that all seven types of design input have been seen in both Project LTM and Project Solar-Design, but only once the design stream moved beyond mere concepts and into actual prototypes. Initial "paper" design studies, notably the first design iteration in Project LTM, are for instance unsuited for obtaining insight into practical issues.

Furthermore, this intermediate reflection added an eight type of design input:

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[1] Tempelman, E. and Adamovic, N. (2015): Experiences from recent European research projects on the interplay between technology and design, Design Management conference, Pisa, Italy, June 23-26th 2015.
[2] Nathan, A. et al. (2012): Flexible Electronics: The Next Ubiquitous Platform, Proceedings of the IEEE, Vol. 100, May 13th 2012, p. 1486-1517. NB: this paper appeared in print one week after the submission deadline for the LTM project proposal.

“One point missed in the list [see above] is the **risk of over-specification, which designer involvement can help avoid**. Material scientists tend to focus on performance elements that may for actual application not be that relevant. A case in point is the LTM material thickness: technologically it is possible to go as low as ~0.5 mm […] yet for none of the product concepts explored so far are such extremely thin versions required. Another example, one that is obvious in hindsight but was not so clear before the project, is that for many conceivable applications, the LTM materials do not need to possess touch sensitivity and luminous response everywhere. In Project Solar-Design, this issue of over-specification also comes to the foreground: for many designs, high efficiency – one of the hallmarks of success in the world of PV, and often the only parameter reported in the press about breakthroughs in this field – is really […] much less important than many people think, at least if actual product applications are being considered, not flat panels for […] solar farms.”

This conference paper completes the intermediate reflection on the type and extent of design input on the materials RTD. Below, this influence is further articulated, first in terms of the concrete RTD outcomes (section 4), then in terms of the RTD process (section 5).

4. Evidence for design input on materials RTD: results

4.1. Piezo plastics

For the piezo plastics, the expected “requirements for geometries, levels of touch sensitivity, and matrix materials” were indeed articulated during the course of the project, through design research in WP1 and – stronger so – design practice in WP3. This was, however, not always easy going. For instance, the target flexibility (see Table 1) provoked lengthy discussions, with the scientists struggling to convey their viewpoint to the designers, and vice versa. It became clear that the material property of stiffness (Young’s modulus) does not readily translate to the design domain. Specific “lollypop-samples”, made for a specific designer-scientist exchange during workshop 6 (Barcelona, Sept. 2014) helped communicate and translate the point across. Similarly, the difference between elastic and plastic deformation was a source of some confusion. Once it was expressed in forming potential – single curvature is enabled, double curvature not – this became better understandable.

It is key to note that by itself, a piezo plastic (technically, it is a structured composite of piezo-active particles in a polymeric matrix, but “piezo plastic” will do as shorthand) is not an actual touch-sensitive “material”, but merely the main component of it. To sense touch, it requires wiring, charge amplification, and a suitably-programmed IC; it also requires a specific lay-out and materialisation to maximise performance (not deformation in compression, but in bending or twisting) and to exclude unwanted side-effects, such as pyro-electricity and signal noise. While designers tend to see these elements as challenges for material RTD, the scientists see them instead as part of integration work.

Even so, design input for the “pure” materials RTD work on the piezo plastics has been significant. Of particular importance to mention is that the breakthrough on lead-free piezo plastics, which was attained in the second half of the project and still forms the target of continuing effort, was experienced very positive by the designers. It is a matter of some debate if this breakthrough might also have been achieved without design input, but the mix of interests that typifies the LTM project has certainly added weight to the issue and sped up the research agenda.

During the project, it became clear that only few product concept designs require the LTM materials to combine touch sensitivity and luminescent response everywhere over their surface. Instead, potential applications often have input and output at different locations. This means that the “look and feel” of the piezo plastics also becomes a variable that is open to design input. However, since these qualities can also be realised with coatings, it does not readily translate into actual material requirements in the manner that, for example, design input on flexibility, sensitivity, or cost levels does.

4.2. OLEDs

For the luminescent layer of the LTM materials i.e. the OLEDs, design input has indeed taken the form of specifying "desired shapes, sizes, and luminescent output colours". Interestingly, the base shapes generally used by the Holst Centre (square tiles etc.) turned out to be not that interesting for designers. In hindsight, this can be seen to be inherent in the choice to work on signage: if the purpose is to signal or inform users, so, not related to area lighting or high end display functionality, then the targeted 15 x 15 cm squares from Table 2 are much larger than needed. Instead, thin strips or even smaller shapes (e.g. button-sized devices) work well, as used in e.g. the LifeSaver (Van Berlo) or PhysioFriend (Lamb) product designs. And as already mentioned, the thinness of the OLED may be a valuable technological target by itself, but it is not that important for actual designs. With precious few exceptions, the success of product concept designs does not depend on the OLEDs being either 1.0 or 0.8 mm thick.

Targets for luminescent output levels were also supplied by the design stream, but again with a notable difference in terminology: an *X* value of lumens/Watt is a very different way of expressing a development target than demanding the OLED to be clearly visible in outdoors applications.

Of special note was the surprising design requirement implicit in the question "what does the OLED look like when it is off?", which was already raised during the kick-off workshop. Clearly, signage is not always on and hence, the look of the OLED when turned off becomes a variable for design input.

For actual signage applications, possessing some form of colour-changing ability is of obvious importance: countless products have a luminescent element that communicates different states to the user through different colours (e.g. red and green), generally embodied in a single RGB LED, the existence of which becomes an implicit requirement for OLED-based signage. For the OLEDs in Project LTM, this was foreseen, as evidenced from Table 2, but during the first year, the RTD focus was firmly placed on mono-coloured devices. Still, the designers kept the topic on the table. Later during the project, the first transparent OLEDs were produced, and when combined, such OLEDs have inherent colour-changing ability. As with the lead-free piezo plastics, it can be argued that this work would also have materialised without design input, but in the course of the project, the design stream did have a clear influence, if only in helping set priorities for OLED RTD.

4.3. Top layer/colour effects

Foreseen in the DoW was a specific top layer for the LTM materials that would, through phosphor down-conversion, alter the OLEDs base light output colour. This work was of special importance as the OLED base colours are quite limited: while in theory, virtually any colour light can be created with the use of a specific light-emitting polymer in the OLED stack, in practice, Holst has a limited set of colours available (developed primarily for lighting and displays, the two key application areas). Designers may very well desire different colours to work with.

During the project, first trials were done with rhodamine dyes that could indeed create such "colour effects". These trials were picked up once more from Sept. 2015 onwards, once it had materialised that the use of irradiated nano-diamonds to create these effects, while scientifically more interesting than mixing rhodamines in a top layer, was not workable. The design input provided concrete requirements for these trials, and presented clear and inspiring visuals of what such effects could look like (see section 3, item 3: here one can see a good example of such design input in practice). Case in point was the GloBuddy (designed by Fuelfor), which showed that even simple colour effects can make a real difference, and also that this effect can be localized: in this product concept, a small red heart shape was designed on top of a faintly blue base rectangle. Patterns, which can be obtained either by masking off with a top layer or by designing the base OLED itself, were also shown to be quite relevant and valuable, as evidenced by the Hack Roll concept (Minima). Even more intricate design options were used in the Me.Lite headphone concept (Pilotfish), where OLED design begins to touch upon the domain of fashion.

Tactile response was also expected to be modified, but during the course of the project, the researcher involved stepped down and this topic regretfully had to be dropped from the agenda. Up to that point in time, some basic "mixing" trials had been done using silicone rubbers, as planned in the DoW, but the majority of designers considered these to have the wrong feel. This development did however provide some considerations about the process of materials RTD and about how this can or cannot be open to design input, and the apparent failure of the work on tactile response modification has some lessons to learn for DDMI in general (see also section 5).

4.4. Integration

As the project progressed, it became clear that many "material" properties of the LTM materials are design features resulting from the integration of the four distinct technological components into a workable stack, and from how this stack is further integrated into a product – at least, following the terminology of the materials scientists. Robustness is one example, which depends strongly on how integrative challenges such as joining and sealing are addressed, and much less on the base properties of the piezo plastics and OLEDs. Cost is another: except for the most basic of applications (e.g. a 1 x 1 cm square OLED with a simple on-off piezo plastic switch underneath), the cost of the LTM materials is strongly influenced by integration – and of course production volume, which is product-specific and hence, not readily seen as an intrinsic material property. An exchange with the Solar-Design project reveals that these exact same two issues came to light in that project as well.

To some extent, integration can overcome limitations of the base materials. By joining together different OLED panels, size per panel can for instance be overcome as a limit, provided the joints and seams can be made to "work" from a design point of view. In this way, it is even possible to create double-curved products even though individual elements are basically flat. So, integration simultaneously emerged as a challenge and as a solution.

All in all, the projected integrative work really focused on this "integration into products", i.e. the second item identified under section 2 above. As just explained, the work on aesthetical and functional top layers did not really materialise, and upscaling studies are still on-going.

Design input for integrative RTD work that was not fully anticipated in the DoW concerned the requirement to include additional input- and/or output elements. Several designs were put forward that rely on e.g. angle sensors or accelerometers in addition to piezo plastics for input. Similarly, for output, additional functionalities were considered and requested (e.g. audio, vibrating). So, on this count, there was clear evidence of design input – with the proviso that this did not constitute actual material RTD, at least under the terminology of the materials stream. Not anticipated at all was the work towards "design for the circular economy" in the design stream (around June 2015), which led to the requirement that all integrated components could be easily disassembled for reuse, refurbishment and recycling: this is perhaps the strongest unplanned example of design input on the integrative RTD work (illustrative design: Buddy Sleeve by Diffus/DUT-IDE).

The temporal behaviour of the LTM materials, in other words, how they turn on or off over time, also depends on integration: in response to touch, the OLED part of the materials can turn on suddenly or slowly, or flash or pulsate, all as desired. All that is really needed is a suitably-programmed IC, as the OLED can in principle dim to any level between zero and its maximum output. Significant time was spent on discussing this "temporal quality", with the design research partners getting involved and the project as a whole making some first steps towards defining the required new terminology and design language. One could say this is a case of design research being driven by materials RTD, with design practice being the intermediate partner.

A final reflection on integration: during the project, electro-luminescent (EL) materials were frequently used as stand-in for the flexible OLEDs during the design work. However, EL uses high voltage, high frequency, and this does not go together well at all with the very sensitive piezo plastics. OLEDs, which operate at low-voltage direct current, generate much less interference problems, and consequently are easier to combine with piezo plastics. In hindsight, this conclusion may seem obvious to anyone with a signal processing background, but it is a fact that this part of the LTM materials' unique value proposition (UVP) was discovered during the project, not before, and furthermore, that it was discovered through concrete design work.

5. Evidence for design input on materials RTD: process

With the "why" of DDMI as given, the above has primarily considered the "what" i.e. what were the initial targets for design input in the materials stream, and what came out during the project. To complement that assessment, this section reflects on the "how" of this interaction, so on the process of material RTD and on how this was affected through exchange with product design.

5.1. People

The first of these reflections concerns the individual researchers involved. Already in setting up the LTM project, the WP leaders were aware that the particular exchange between designers and scientists would make specific requirements on both sides. This had immediate consequences for the materials stream[3]. Staff members with a typical "hard science" mentality, focusing on material models and academic output, and crucially, having a limited desire to share their findings with people outside their immediate environment, would not have been in the right research environment in this project. Rather, more open-minded scientists were called for, who were willing to do some extra explaining when this was needed (which it often was) and to interact with people who have a very different background. Where possible, staff members were selected or hired accordingly, and this represents a definite result of design input on the process of materials RTD.

5.2. Samples

Secondly, already from the project's kick-off, the design stream made its requirements clear to have available plenty of samples of the materials to-be-developed. Indeed, this was also reflected in the DoW, with specific tasks formulated to that end. Consequently, especially the scientists working on the piezo plastics worked hard to meet this need, often putting off more regular research activity (model-building, making theoretical advances, creating academic output etc.) until later. Again, one can see a clear design input on the RTD process.

Here it is of value to add that the product designers "always wanted more", but were not in any position to judge the difficulty of what they were demanding in terms of quantity. The problem was augmented by the fact that in Project LTM the designers outnumbered the scientists roughly two to one. This naturally led to some friction. On the positive side, the designers tended to be satisfied much sooner than scientists when it came to sample quality. For instance, OLED homogeneity hardly matters to them (it does to OLED scientists). Indeed, even "failed" samples were often of value to the design stream, for instance, to illustrate flexibility levels, or to evaluate joining options – a clear illustration of the "lateral thinking" that designers bring to the arena, and that helped WP4 forward.

[3] As well as of course for the design stream, but that is a topic for a different reflective document.

5.3. Synergy

As noted above, the RTD work on tactile top layers was not successful, and was abandoned midway during the project. This might be attributed to personal differences, were it not for the availability of a better explanation: there simply was insufficient overlap between the work that the scientists involved needed doing for the project, and the academic responsibilities they were facing outside of the project as well. Under EU FP7 rules, the project's RTD work is only partially funded, and creating such overlap – so, creating synergy between tasks – is therefore an essential success factor for DDMI to take place. For the tactile effects, this synergy seemed not to materialise.

5.4. RTD agenda-setting

The piezo plastics developed at DUT-NovAM have the pleasant benefit that there is an existing material much like it (PVDF) – it's just not as good in terms of thermal resistance or price. This makes it easy to convey what the new materials will really be like. For the flexible OLEDs developed at Holst, a comparable "stand-in material" is EL foil, which possess many of the qualities of flexible OLEDs, with the latter being brighter, more efficient, and so on. During the project, it emerged to Holst that there is a real need for them to also invest in EL technology, if only to show what the final product – flexible, roll-to-roll printed OLEDs – can be like. So, RTD agenda-setting as a result of DDMI.

5.5. Motivation

Under the current topic of process, a closing reflection concerns the motivation of the individual scientists. Generally, the materials scientists involved in the LTM project were pleased with the design attention, and enjoyed the prospect of seeing their materials come to the market, or at least, getting a concrete idea of how the results of their efforts could one day be used. Several scientists also expressed their appreciation for getting to know the way in which designers work (e.g. how product can tell stories, or how trend forecasting works). All in all, the "design-materials dialogue", while often difficult and always time-consuming, was perceived as positively motivating. One might argue that the scientists were selected to have this disposition to begin with, but still it is a valuable reflection to add. Materials RTD is often abstract and seems to get increasingly detached from day-to-day worldly concerns – in Project LTM, it surely was not the case.

6. Conclusions

While materials RTD is experienced "inside-out", design and designers look "outside-in". In terms of the former, the LTM materials are not a material per se but a combination of materials, components, and even software that in terms of the latter behaves as a single interactive material. Consequently, much of the design input in the materials RTD stream is actually integration input, bypassing the pure materials-related work. Still, project LTM has shown clear evidence of design input in the materials stream. Lead-free piezo plastics, transparent and colour-changing OLEDs are the key elements of this input. Process-wise, there was also clear influence on the people involved in the materials RTD stream and on their priorities for work, with a strong need for samples being the most direct example of the latter. Furthermore, design input underlines the need to have showcases of "what the technology can look like", influencing the research agenda in general.

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