frontiers | Frontiers in The Internet of Things

TYPE Review
PUBLISHED 19 February 2024
DOI 10.3389/friot.2024.1321263

OPEN ACCESS

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RECEIVED 13 October 2023
ACCEPTED 29 January 2024
PUBLISHED 19 February 2024

CITATION
Lebloch K and Rafetseder A (2024), Laying foundations for a "Right to Improve".
Front. Internet. Things 3:1321263.
doi: 10.3389/friot.2024.1321263

Laying foundations for a "Right to Improve"

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In this work, we introduce the vision of a "Right to Improve": a hypothetical future law which should entitle consumers to modify and extend Internet of Things devices during the productive lifetime. Current European Union legislation as well as voluntary manufacturer interoperability initiatives fail to address user desires for adaptability, augmentability, and open-ended repurposing of Internet of Things (IoT) devices. We therefore argue in this paper for a Right to Improve that aims to fill the gaps left by today's laws, conforms to consumer demands, and is powerful enough (by its statutory nature) to cause actual change. Our contribution is twofold. First, we summarize the relevant legislation (Ecodesign Directive, Sale of Goods Directive, and Right to Repair). We review the academic literature, and highlight technical and motivational factors that support a Right to Improve. Second, we suggest and discuss a number of open problems in need of consideration by academics, practitioners, companies, governing bodies, and the general public. A future formulation of the Right to Improve should take into account and balance the various contrasting views for efficacy on different levels, e.g., environmental benefit vs. economic risk. Change enabled by a Right to Improve may greatly enhance the usefulness of devices during their use phase, empowers consumers to create and compose devices and services to their own taste and requirements, makes devices more economically and ecologically sustainable by extending their useful lifetime, and creates new business opportunities.

KEYWORDS

Internet of Things, sustainability, legislation, improving, long-term-availability

1 Introduction

The IoT is a recent development around networked physical objects, oftentimes called "Things," which use local networks or the public Internet to interconnect and provide parts of their functionality, e.g., remote control and sensing. The IoT nurtures a huge market across many domains and is a place for diverse innovation. IoT devices abound in the industry as well as in offices and private households. They provide "smart" functionality, and can even help to increase the overall energy efficiency and electrical energy generation-consumption balance.

All is not well, though. The currently prevailing way in which manufacturers build their IoT devices ensures that the devices stay under strict control of the manufacturer, are often useless without resorting to the manufacturers' smartphone app and cloud services, and generally lack interoperability and updatability and thus, resilience. This is particularly problematic once the manufacturer loses interest (due to offering newer devices and phasing out support for older ones), or goes out of business altogether: this "software obsolescence", as a recent report from the German Environment Agency (Umweltbundesamt) by Jaeger-Erben et al. (2023) calls it, can result in the end of the useful life of an IoT-enabled device. This is a truly bizarre situation, as the device may be in perfect physical shape and working condition—only its separation from the manufacturer's cloud services causes it to stop functioning!

This situation is both bad for the environment (De Roeck et al., 2012; Stead et al., 2019) due to the quantities of forcefully software-obsoleted devices, and disappointing for consumers (Brush et al., 2011; Offermans et al., 2013; Casado-Mansilla et al., 2019; Salovaara et al., 2021). Thankfully, there is hope, and demonstrations of IoT's capability to be improved on can be found: improvements of the required sort are technically well feasible and within reach of capable audiences (Ramakers et al., 2016; Ravi et al., 2020); standardization (Lagally et al., 2020) exists; visionary ideas (De Roeck et al., 2012; Stead et al., 2019) suggest inventive forward paths. Also, the current market allocation rewards the passivity of commercial actors whose market shares are established and "walled gardens" already inhabited by paying consumers. There is no economical motivation for these actors to unlock and open up their products for after-the-purchase improvements by third parties, including consumers. The legal situation in many countries has started to adapt to the End of Life problem at least, the European Union's Right to Repair (EU, 2023) being a very recent example.

1.1 Aim and scope

Instead of the current problematic state of affairs, we wish for IoT devices that are both environmentally friendly (e.g., help to conserve energy, stay useful for as long as physically possible) and supportive for the user (e.g., interoperate easily and reliably, function independently of the manufacturer's service offers). Despite the principal technical feasibility and the existing legal frameworks, the Internet of Things does not appear to be following this trajectory.

Therefore, we argue that a consumer Right to Improve should be implemented. It shall ensure provisions for adaptability, augmentability, and open-ended repurposing by consumers from market entry onward. In contrast to the Right to Repair which targets to postpone the product End of Life, these design changes will affect the use phase of devices. This enhance the device's usefulness, empower consumers to create and compose devices and services to their own taste and requirements, make devices more sustainable by extending their useful lifetime, and create a deluge of new business opportunities through this. Thanks to their properties, the IoT and its devices can serve both as the motivational starting point and the vehicle for a practical implementation of a Right to Improve.

The Right to Improve should act as a legislative commitment towards furthering the goals above. Its effect should be a shift in design paradigms towards a clear separability of the immutable and more dynamic properties of appliances. In the case of IoT, these would be the hardware and software/service properties respectively. Separation allows to keep up with technological advancements, while keeping functionally adequate physical components in use for as long as possible.

While the Right to Improve is only a vision at this stage, it *could*—but we think in our case that it *should not*—build upon "fair use" rights to reverse engineering or hardware documentation as granted by current implementations of the Right to Repair, the Digital Millennium Copyright Act (DMCA) [105th Congress (1997–1998)], and similar laws: the issue with these rights is that they put the burden on the consumer or third-party repairer to actually develop an interface, a development which needs resources such as technical skills and equipment that only specialists possess.

Instead, we foresee that the Right to Improve might want to prescribe that manufacturers provide an open control interface on every device. To illustrate the idea of a Right to Improve for IoT devices, this interface could enable access to the same functions that the device's main User Interface provides, be it physical buttons and displays or any form of remote control. The consumer then attaches a controller or bridge adapter to the interface, and can then use the device independent of the manufacturer's default interface modalities and envisioned service concept. The adapter itself might be the original manufacturer's, a third-party product, or even self-developed.

Even though we theoretically consider the Right to Improve's scope to eventually encompass all kinds of appliances and their features, our expertise focuses on the domain of the IoT, where we identify a particular incidence of premature obsolescence brought along by the immutable design of potentially dynamic properties. Extending the scope of the Right to Improve beyond the IoT would of course presuppose the inclusion and contributions of respective domain experts in order to define realistic and achievable goals.

The actual form and contents for a Right to Improve, for IoT devices as well as devices in general, is to be developed yet.

1.2 Contributions

Figure 1 overviews the frame of our paper. Our paper presents our vision and lays the foundations for a Right to Improve—a yet-to-be-defined, new law that ensures adaptability, augmentability, and open-ended repurposing of devices during their use phase by consumers –, and presents open questions for its implementation. The vision for a Right to Improve is argued from two starting points:

One, we summarize (§2) the relevant European Union sources of law, i.e., the Ecodesign Directive (EU, 2009), the Sale of Goods Directive (EU, 2019b), and the recently proposed Right to Repair (EU, 2023); we also note that European Union legislation has an effect in other territories.

Two, a study (§3) of Computer Science literature on IoT (chosen as a representative example of physical devices dependent on principally malleable software) discusses the points of view of technical feasibility (improvability, modifiability) and consumer motivation (user criticism of current IoT technology, and desirable futures).

The legal and technical-academic strands are brought together in §4. This shows that the goals of a Right to Improve are both technically achievable and also wanted by users of IoT. While suggestions and first implementation steps towards addressing the criticism and needs have been made, and some industry and community initiatives exist for opening up interfaces, the scope of the latter is very limited. No legislative approach to solving the issues at hand is available currently or has been proposed yet.

In §5, we turn to the problem of delineating the extent and effect of a Right to Improve in practice. We do not offer definite answers here, but try to identify different issues (and possible ways of deciding them) as starting points for future discussions and considerations. The paper concludes in §6.

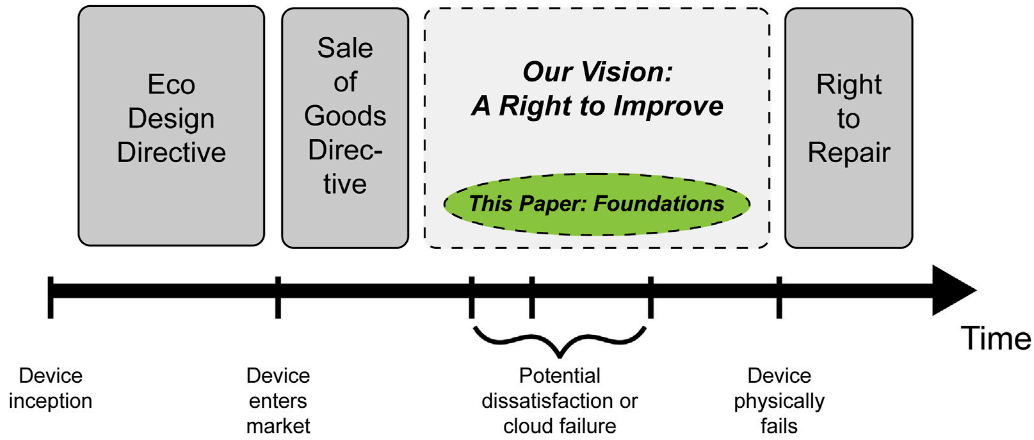

FIGURE 1
Overview of (from left to right) Ecodesign Directive, Sale of Goods Directive, Right to Improve (our vision in this paper), and Right to Repair projected onto the life cycle of a device.

1.3 Limitations of this work

Our paper is limited by focusing on the European Union legal framework (§§2.1–2.3) and disregards both member-state or national laws as well as existing laws for repairability in other countries such as the United States, Canada, Brazil, or India. The breadth of the literature (§3.2) represented is constricted, both by our chosen scope on IoT, and the available space. We discuss criteria for inclusion in §3.1. Since we anticipate that the Right to Improve will be a consumer right, we emphasize residential IoT over Industrial IoT (IIoT), Smart Cities, Smart Mobility, and other contexts throughout. Parts of our interpretation of the literature results (§4.3) are restricted to discussing the absence of evidence, i.e., we found few to no sources making a particular point, and the point in case is missing from those sources we did find. This does not rule out the existence of literature that states the contrary, only our search strategy did not discover it.

Lastly, this paper presents a vision of the Right to Improve, and lays foundations upon which a discussion process towards a legal implementation can be based, but does not propose very concrete contents, forms or implementations for a Right to Improve. Although we believe that a Right to Improve is a likely development indeed, we acknowledge that there are still many more open questions in need of discussion than we state in §5. The actual implementation is subject to political process which is informed, but in its course not led, by academic researchers such as ourselves.

2 The European Union legal framework

The current European Union legal framework regarding sustainability and consumer rights when it comes to Commercial Off-The-Shelf (COTS) appliances is applied to different phases of the product life cycle. This section present the respective directives and their recitals (i.e., reasons for consideration), and classifies them according to the product life cycle. The Ecodesign Directive (§2.1) applies to the design phase of a product, well before market readiness. The Sale of Goods Directive (§2.2) assures consumers a working product for a limited amount of time. The Right to Repair (§2.3) applies to the End of Life phase of a product, extending its life cycle for as long as economically viable. Finally, §2.4 turns the attention on the effect of European Union legislation on non-European Union countries, a dynamic to be considered if a Right to Improve should enter into force as a European Union-only law.

2.1 Ecodesign directive

The Ecodesign Directive (EU, 2009) directly applies to the design phase of all products relevant to energy consumption, obviously including IoT devices, as energy is necessary to establish communication and function according to purpose. It sets requirements for product designs regarding their sustainability and environmental impact. Among the recitals for the Ecodesign Directive, the European Commission states the goal of reducing said impact throughout the entire product life cycle, from resource selection to End of Life of the product. In order to achieve this goal, specific ecodesign requirements should be defined for specific product categories in order to minimize the environmental impact. The Ecodesign Directive requires member states to monitor products according to whether its requirements have been met and to take action if violations have been detected (such as prohibiting the product in question from being sold)—and notify the other member states upon detection. If a major potential for reduction of the environmental impact at relatively low cost has been detected for a specific product category which was sold at a sizeable amount of at least 200.000 units a year, it shall be covered by an implementing measure or a self-regulating measure, where manufacturers themselves create ecodesign criteria to adhere to. There are currently 8 binding implementing measures[1] regarding the

1 A category for mobile phones, cordless phones and tablets is under implementation.

ecodesign of products in the European Union for the following product categories, most of which currently are available as IoT-enabled appliances:

1. Household washing machines and household washer-dryers
2. Household dishwashers
3. Refrigerating appliances with a direct sales function
4. Refrigerating appliances
5. Electronic displays
6. Welding equipment
7. Vacuum cleaners
8. Servers and data storage products

Next to functional requirements regarding the energy and resource (e.g., water) consumption of products in these categories, the implementing measures include directives for repairability such as which replacement parts and manuals must be made available, and to whom. The Right to Repair (see §2.3) references back to those measures for repairability requirements and replacement part availability. While printed circuit boards and reset software are listed as replacement parts, there is no further mention of communication hardware and software built into these appliances, nor an anticipation of software End of Life which may well predate terminal defects of the physical (rest of the) appliance itself.

2.2 Sale of Goods Directive

The Sale of Goods Directive (EU, 2019b) aims at the beginning of the use-phase of a product, and guarantees the consumer a minimum timeframe during which the product has to provide functionality according to the sales contract. Sales contracts in this context also include update cycles, and the fitness of a product for its purpose. This directive also assures the consumer, that the product can fulfill the purposes for which other products of the same type may be used. Most importantly, the Sale of Goods Directive requires goods provide the functionality, compatibility, security, and durability for a reasonably expectable amount of time given the nature of the good in relation to other goods of the same type. Should the good lack conformity with the sales contract (such as failing too early or losing compatibility), the consumers are entitled to repair or replacement or in some cases even price reduction or refund. This is often also referred to as “dealer warranty,” since the vendor is the party approached by the consumer in such cases.

2.3 The Right to Repair (Directive)

The Right to Repair Directive (EU, 2023), announced in April 2023 by the European Commission, targets the End of Life phase of a product. Its stated goals and purpose is to prolong the use phase through repair upon a fault. The Right to Repair, as proposed right now, grants consumers the right to request repairs for products directly from the manufacturer “for free or against a price or another kind of consideration,” The requested repair can be executed by sub-contractors or the manufacturers themselves. In addition, the Right to Repair requires manufacturers to provide access to spare parts and repair-related information to independent repairers. All of the requirements and rights apply only to the list of product categories laid out with specific implementing measures in the Ecodesign Directive (§2.1). As a result, a large number of potentially smart appliances, such as HiFi systems, sensors, or HVAC systems are not covered by the current version of the Right to Repair.

2.4 The impact of European legislation abroad

Since we envision the Right to Improve to take shape as European legislation in the form of or as part of a directive or regulation, its impact may reach even beyond European borders. There are many examples demonstrating the reach of European legislation influencing legislation abroad such as recently concerning the General Data Protection Regulation (GDPR), which lead to other countries elevating their privacy standards to European levels. Specific manifestations of this so-called “Brussels Effect” (Bradford, 2019) can be observed in the European Commissions adequacy decision on, e.g., Japan (see EU, 2019a), as well as California’s own implementations of data protection laws CCPA and CPRA (see California State Senate, 2018).

While the reach of European data protection regulations is certainly notable, other domains have also been subject to the “Brussels Effect,” as documented by Bradford (2019): The Restriction of Hazardous Substances (RoHS) has impacted product design of COTS hardware across the globe, as manufacturers begun adhering to the higher standards set forth by the EU due to the implied organizational overhead of maintaining two different product and production lines (RoHS compliant, and noncompliant).

Most recent, and perhaps most relevant to the discussion is the European Union’s latest success in enforcing consumer electronics standardization regarding mobile phone charging hardware. Directive 2022/2380 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment EU (2022) mandated adhering to the USB type C standard as charging interface, which led the last sizeable non-compliant manufacturer, Apple Inc., to bring its 2023 model of the iPhone to market equipped with the required USB type C port instead of the proprietary connector found on earlier models of the device.

In essence, we expect that a European Right to Improve may have a similar impact on the global market for IoT devices, due to the simplicity of maintaining only one product line globally as observed with RoHS. The implied benefits of the Right to Improve could thus also be experienced by users across the globe.

3 Technical and motivational foundations for a “Right To Improve”

In this section we review the academic literature on IoT with specific respect to its technical malleability–i.e., its quality to allow customization, adaptation, and conversion–regarding device features and service provision, openness to modifications, and

TABLE 1 Literature databases consulted, search terms used, and number of items found during the systematic search.

Database	Search terms	# of Results	Phase
ACM Digital Library	"Internet of Things" AND retrofit	232	
	"Internet of Things" AND upcycle	16	I
	"Internet of Things" AND tinker	123	
	"Right to Repair"	44	
	"Ecodesign Directive"	17	II
	"Sale of Goods Directive"	0	
IEEEXplore	"Internet of Things" AND retrofit	79	
	"Internet of Things" AND retrofit AND "Smart Home"	7	I
	"Internet of Things" AND upcycle	0	
	"Internet of Things" AND tinker	5	
	"Right to Repair"	8	
	"Ecodesign Directive"	39	II
	"Sale of Goods Directive"	0	
Total Hits Phase I		462	
Total Hits Phase II		108	

repurposability, as well as concerning the views and desires of IoT users.

3.1 Method

To gather material for this section, two phases of literature search were conducted in two online databases[2] of academic literature on Computer Science and Electrical Engineering. The searches were performed in the second quarter of 2023, and search results (papers, posters, opinion pieces, editorials, workshop descriptions, etc.) stored for later analysis. A rough selection for further analysis was performed by evaluating titles and abstracts. For works deemed relevant to our analysis, additional literature references from within these papers were followed. In other cases, we reviewed other works by authors of papers on our initial results list, and checked proceedings from other editions of conferences (such as *CHI*, *BCH*, or *IoT*) that had yielded interesting sources. Wherever this approach seemed to leave areas underdeveloped, we considered additional sources (e.g., on industry initiatives) outside of the structured search. The papers were then curated, read, summarized, and then categorized by topic to form the basic structure of the Results section (§3.2) below.

In the first phase, the search was refined iteratively: "Internet of Things" by itself is too generic a search term (yielding over 100 k results across the two databases). Restricting searches by adding "improve" or "interface" only cut down the volume to one-third of that. Therefore, the search was combined with "retrofit," "upcycle," and "tinker" instead. Our hope with these additional search terms was to capture the idea of IoT device augmentation on the manufactured product (instead of, e.g., conceptual suggestions for ground-up new designs). This resulted in a manageable number of results and a more reasonable proportion of papers relevant to end user and technical improvement matters, concretely 462 results from the timeframe 2012 to 2023 (See Table 1).

The initial preselection was then conducted based on the elimination of duplicates and on (lack of) relevancy to the topic at hand as deductible from the titles, and in cases of doubt from the abstracts of the papers. For example, we excluded papers discussing technical performance optimizations or system architectures. This step resulted in the selection of 85 relevant references for retrieval and yielded the largest share of papers referenced in the rest of this work.

In the second research phase, we analysed the legal frameworks and additionally searched both literature databases for publications relevant to the legislature. Results for the search term "Right to Repair" yielded many false positives from the automotive sector or from sources using the phrase without referring to legislations of the same name. Literature concerning the Ecodesign Directive was entirely focused on energy efficiency which is off-topic for us. The fact that the Sale of Goods Directive is aimed at vendor liabilities as opposed to technological aspects may serve as an explanation as to why there are no hits in either of the databases for the term.

3.2 Results

We proceed to review the combined results of the literature search. For this, we rearrange them according to their approximate

2 https://dl.acm.org/ and https://ieeexplore.ieee.org/, accessed 2023-05-08.

topic, and summarize their content. This section presents the categorized findings non-normatively and lays out the factual basis for the arguments made in §4. The categorization was made according to the respective contributions to the technical and motivational factors aligning with our vision for a Right to Improve.

3.2.1 Retrofitting

Retrofitting means extending and equipping existing hardware with additional capabilities it did not possess prior to the modification. In the case of IoT, retrofitting often (though not necessarily) concerns adding sensors and network interfaces to a device with physical actuation capabilities. These modifications are performed "after the fact," on an otherwise finished product, and without support of the original manufacturer. This process is observed in IoT literature for both industrial as well as residential contexts, and some examples are summarized below. The findings serve as support for our argument for the technical feasibility of creating a Right to Improve compliant interface and technical challenges that motivate it in §4.

Researchers have described retrofits of individual industrial equipment for the Industrial IoT (IIoT) by professional workers: Erdani et al. (2021) show how a lathe is retrofitted with stepper motors controlled by a Raspberry PI computer in order to create a network-connected "semi"-Computer Numeric Control (CNC) machine. The process of retrofitting an aluminum foundry with IoT technology following human-centered principles by applying a Design Thinking approach is described by Ermini et al., 2021; Bjetak et al., 2019 present an approach to augmenting industrial Programmable Logic Controllers (PLCs) with temperature sensors. By combining internal PLC and sensor temperature readings, enhanced awareness features are enabled in a Cyber-Physical Production System.

Specialized technology or knowledge is applied in smart home research projects in the following papers. An application concerning the residential IoT context is described by Ravi et al. (2020): Researchers retrofitted a home with a smart door locking mechanism and sensors for gas leaks, temperature, as well as water level monitoring. An approach utilizing physical user interfaces and specialized technology is proposed by Ramakers et al. (2016). The existing user interface (e.g., Buttons, Status LEDs) of an appliance (a toaster in the presented case) is 3D-scanned and physically duplicated using a 3D printer. The original interface is then controlled by actuators, and also made available digitally through a companion app, while still being available via the physical duplicate. Li et al. (2019) tackle coarser physical interactions with appliances such as adjusting the arm of a desk lamp: These are retrofitted with 3D-printed parts, motorized and automated. An "upcycling" approach is presented by Williams et al. (2019): stickers with embedded Radio Frequency Identification (RFID) tags are attached to existing household inventory as input interfaces, thus assigning new meaning to items and imbuing them with upcycled value.

3.2.2 Interoperability initiatives

There are a few initiatives backed by standardization bodies or industry currently working towards facilitating interoperability between IoT devices. Their contributions support our argument for the technical feasibility, and prove the institutional efforts in the discussion section of this paper.

The Web of Things (WOT) recommendations (Lagally et al., 2020) by the World Wide Web Consortium (W3C) define an abstract architecture for manufacturers to improve interoperability of IoT devices across platforms. Its main idea is to orient the addressability of Internet of Things devices along the lines of Web technologies and allow for access to their resources similar to how Application Programming Interface (API)s are used in the Web. This is facilitated by assigning all features of devices into the categories "Properties," "Actions," and "Events" and defining a specific endpoint for each of them. The WOT does not require a specific protocol to be used, but it can only then start being useful, when a device is connected to the internet already. Within the space of manufacturer conglomerates, most recently the Matter/Thread standard (Connectivity Standards Alliance, 2022) from the Connectivity Standards Alliance (CSA), having been released in fall 2022, renewed the promise of manufacturer-enabled true interoperability through a shared protocol and radio standard for new IoT devices released by its partners (e.g., IKEA, Philips Hue/Signify, EVE, and many more).

3.2.3 User experience

Various papers investigate the state of Smart Home technology with regards to its usefulness and usability for users. The literature stemming from the systematic review regarding retrofitting, tinkering, and upcycling discusses the experiences of users of current IoT technology with one of these processes and exposes a tendency to criticise the *status quo*. That is not to say users are not happy with their smart homes as shown in a pre-study by Förster and Block (2022): A high degrees of general satisfaction with current smart home technology is identified amongst the participants, whilst still leaving room for improvement in terms of cost, security and privacy. The results from this subsections help motivate the Right to Improve from a user perspective in §4.

A study on Smart Home usage in four families is reported by Salovaara et al. (2021). The researchers find that despite "extensive facilitation, families faced difficulties in identifying needs for smart-home automation, except for social needs [. . .]," that is: the Smart Home systems used by the families in this study provided little convincing use cases to begin with, nor did it support use cases identified by the families, e.g., splitting household chores fairly. Offermans et al. (2013) show a context-aware hybrid lighting solution based on Machine Learning and manual input and evaluate it with test users. The users see no benefit in the automated system over manual control, and are disappointed by the lack of user authority and insight into the system's reasoning for automated lighting scene activation. In another user study conducted by Casado-Mansilla et al. (2019), office coffee makers were augmented towards energy conservation through automation or user information. The evaluation showed that a lack of understandability and control may lead users to become reluctant to using smart devices, and decrease their activity to act eco-friendly. Multiple barriers of adoption for home automation technologies, such as general inflexibility, poor manageability, and difficulties concerning security were identified in an earlier paper by Brush et al. (2011). It also identified a desire of users towards being able to compose household devices themselves.

3.2.4 Visions

In order to overcome the apparent shortcomings of past and present IoT technology, several proposals for future designs have been made. These "visions" will be employed to argue the motivational factors for a Right to Improve in §4 with special focus on the envisioned future and sustainability of the IoT.

Sas and Neustaedter (2017) present a point towards Do-It-Yourself (DIY) as a way to create meaningful things, and proposes implications for future design such as tinkerable transparent open hardware and corresponding DIY kits alongside standardized communication protocols in order to imbue value to things through personal investment. A manifesto for DIY IoT creation containing 13 guidelines is postulated by De Roeck et al. (2012). It provides a strong focus on user-centeredness and support of unskilled users in creating IoT applications. A call for standardization of the IoT network as well as provision of toolkits for individualization in order to achieve faster growth for the IoT and its applications was proposed already in 2011 by Cvijikj and Michahelles (2011). Another manifesto by Stead et al. (2019) was created through design fiction methods for a more distant future of the IoT. Based on the fictional concept of "spimes" (from "space" and "time") rather than IoT Things, this manifesto propagates circular and continuous usage as a tool to achieve sustainable development and handling of IoT technology.

3.2.5 Didactic IoT

IoT kits and prototypes are used in the literature as didactic means to excite creativity or problem-solving and technical skills. The topic of teaching and learning through ideation and design of IoT applications is also well represented. As with other human-centered aspects of the literature reviewed, these findings also serve to support our motivational argument for a Right to Improve in §4 by adding an expert perspective towards openness of IoT devices and its specific benefits.

Recent work by Przybylla and Grillenberger (2021) presents an extensive model for use in teaching embedded systems to children in K-12 education. A building block for constructionist learning is introduced and used by Arora et al. (2019). These so-called DIOs are small sensor/actuator type wearable gadgets for children aged 8–12. DIOs can be linked to each other in order to create multi-user interactions. Another concept for linkable gadgets is shown by Kurze (2021). The gadgets named "Loaded Dice" are cube-shaped IoT-enabled sensor-actor units equipped with either input or output features, and can be used for the creative ideation of usage scenarios. Finally, Cuartielles (2020) documents experiences teaching about the IoT with different experimental or commercial kits in order to point teachers, educators, or curriculum creators in productive directions.

3.2.6 The Right to Repair

The Right to Repair is a very recent topic, therefore its academic prevalence is low so far. Also, we discard sources which 1) use the phrase "Right to Repair" to describe a (practical, singular) permission to repair a specific broken device rather than the (universal) law of the same name, or 2) refer to an identically-named United States state law pertaining to automobile repair only. This leaves us with the following relevant publications tying into the regulatory motivation for a Right to Improve discussed in §4.

An opinion piece by Schultz (2016) asks whether we are on the way towards an "Internet of Things we do not own." It argues that the classical meaning of ownership of devices–which gives the owner far-reaching rights on use, modification, repair, and resale–is undermined by manufacturers issuing time-limited licenses which are restricted to device use only. "IoT" in this article signifies Internet-connected devices in general, not necessary "Things" with sensors and actuators in the stricter sense.

A large-scale Human-Computer Interaction (HCI) literature study by Roedl et al. (2015) argues for a conception of users as active agents well capable of and motivated to adapting, modifying, and repurposing technology, i.e., as "makers" and "hackers." It draws parallels between enabling repair of devices and enabling improvement through users, and categorizes makers as well as their acts of making, hacking, and appropriation as political (Roedl et al., 2015, §3.4). An implication that underscores the importance of targeting political conditions rather than relying on each individual to empower themself is given in (Roedl et al., 2015, §4.3): "if researchers want to support making, in addition to developing more functional, inexpensive, appropriable, hackable, useable (etc.) technologies, they should also support the construction of a legal, aesthetic, and socioeconomically viable infrastructure in which making can more fully flourish."

4 Discussion

This section brings together our results on European Union legislation and the literature review. It first identifies gaps in the legislation (§4.1). Then, in §4.2 we consider positive evidence for the technical feasibility and actual user demand regarding an IoT that is adaptable, malleable, and easily improvable in an open-ended fashion. These form the technical and motivational foundations for the Right to Improve. §4.3 points out areas that we think the literature does not cover sufficiently, but the Right to Improve should: aiming for actually changing the market and the marketed COTS devices, supporting real end users in their plights instead of carefully selected experts, and attacking the issue of device improvability on the fundamental level of legislation instead of one-off, individual, particulate, and partial solutions. Finally, §4.4 summarizes our key findings.

4.1 Gaps in existing EU regulation

Upon analysis of the current and coming legal framework in the European Union with special regards to the specific problems inherent to IoT devices (such as mandatory manufacturer cloud services), we identify multiple gaps for the Right to Improve to fill.

4.1.1 Ecodesign Directive ignores software obsolescence, use phase improvements, extensibility

A gap within the Ecodesign Directive is exists in that restoring a loss of communication capabilities due to software-based obsolescence (be it from incompatibilities, security deficiencies, or immutable service providers) is currently not represented within the ecodesign directive. Moreover, the Ecodesign Directive is not directed at the use phase of a product, e.g., regarding premature replacement of appliances due to loss of consumer satisfaction with the provided feature set or mandatory service provisioning periods. It does also not take the potential for extensible nature of software for additional feature sets for IoT devices into account, a major demand of our proposed Right to Improve.

4.1.2 Sale of Goods Directive is short-time, vendor focused

The Sale of Goods Directive as it is only applicable during a relatively short time frame compared to the average use period of household appliances. It can only reasonably be applied to the first few years of usage on a new product since the burden of proof for the cause of a flaw is increasingly harder to attribute to the manufacturer with passing time and frequent use. Moreover, the Sale of Goods Directive applies to *vendors* first, and the question arises whether and how vendors can be held accountable for deliberate decisions of a *manufacturer* to stop supporting IoT enabled features of an appliance. Additionally, should a manufacturer or vendor go bankrupt even within the warranty period, consumers have no one to hold accountable upon loss of features or dissatisfaction.

4.1.3 Right to Repair focuses on EoL, misses IoT

A gap we identified within the current version of the Right to Repair is its focus on the physical End of Life phase of a product, not the use phase of the device where an entitlement for modifications would be beneficial for users. Furthermore, the Right to Repair is limited currently to the product categories defined by the Ecodesign Directive. This is troublesome, considering the growing diversity of IoT devices in the market today: a lot of products such as thermostats, coffee makers, light fixtures and even HiFi equipment do not fall into an Ecodesign Directive category, and therefore, the Right to Repair fails to be applicable to them at all.

4.2 Technical and motivational factors that align with the Right to Improve

The existing literature provides numerous indications that a Right to Improve can be implemented in current technology, and also why it should be implemented to address consumer needs. These notions support our vision for a Right to Improve by showing that technical changes are realisable, and that a Right to Improve could serve actual user demands.

4.2.1 Technical feasibility

The analyzed technical publications adequately proved the feasibility of retroactively outfitting household appliances or industrial fabrication machinery with communication and computation hardware as well as corresponding digital tools. The discovered solutions for improvement can be further divided into different abstractions: Improvement through interaction with physical interfaces, IoT hardware retrofittings, and improvement through additional software (e.g., middleware):

First, a basic workaround for the problem of missing digital interfaces is to retrofit physical user interfaces by putting wireless servo actuators on buttons and knobs of appliances. This proves to be effective enough for many real world use cases. Still, “bolt-on” duplicate interfaces like presented by Ramakers et al. (2016), while functionally equivalent to a qualified API, present a significant design and manufacturing overhead. Also, recreating the interface is a task which needs to be repeated for every appliance the solution is to be applied to. This approach can thus merely be seen as a tool for very particular problems, especially given the aesthetic impact on user-facing surfaces it creates. Also, interacting directly with a more “coarse physical user interface” such as opening a drawer or adjusting a table lamp has proven to be achievable with current technology as shown by Li et al. (2019). The limitations towards mass adoption of such technology again lie in the bespoke nature of its products.

Second, IoT hardware retrofitting approaches as presented by Bjetak et al., 2019; Ermini et al., 2021; Ravi et al., 2020 show how existing hardware can currently be improved. The tools at hand are readily available sensors and actuators which have to be applied in ways specific to the use case in order to improve or add functionalities to devices. Large scale industrial operations (Ermini et al., 2021) can be realized just the same as medium (Bjetak et al., 2019) or small (Ravi et al., 2020) scale deployments.

Third, while novel middleware or architectural solutions such as shown by Lagally et al., 2020; Shafagh et al., 2017; Dorri et al., 2017 aim to improve general interoperability and to enable cross platform functionalities, they are limited to resources made available to them in an automated fashion via corresponding APIs. Still, these approaches stand as proof of technical ingenuity in making cross-platform services and analytics available through software, with all of the benefits that come with it. The Right to Improve could establish itself as an enabler for powerful middleware capable of integrating IoT devices from a common household into a unified service.

4.2.2 User motivation

Next to the basic proof of technical feasibility of upgrading existing hardware, motivation for easier access to device interfaces can also be found in the literature discovered. We again partitioned the papers into three abstract categories representing different motivations for an open IoT: Sustainability, Empowerment, and (quality of) interaction.

In order for IoT technology to become sustainable, long-term use and resilience of functionally sufficient devices is mandatory. While not directly interfacing with the devices themselves, the IoT Stickers for an “upcycled IoT” by Williams et al. (2019) show clear motivation for long term use of not just IoT but any hardware. Adding new functionality to already existing inventory may facilitate extended use, and in the case of the IoT Stickers may also change the perception of the items in question and assign new uses altogether. Stead et al. (2019) even goes as far as to openly demand design for perpetual use, in a cradle-to-cradle approach. A stipulation hard to fulfill even with modular approaches given evolving and thus sometimes deprecating standards and the fact that obsolescence is immanent to devices at some point in time.

Another motivation for a Right to Improve found in literature may be empowerment of users to create, modify, or extend their devices according to their personal needs. As far back as 2011, Brush et al., 2011; Cvijikj and Michahelles 2011 already identified a desire of users to compose or customize IoT devices, which can be satisfied by supplying standardized interfaces and toolkits for individualization. De Roeck et al. (2012) also postulates a need for supporting unskilled users in creating IoT technology, a task being made difficult given the current market situation without a Right to Improve, since tinkering with hardware not designed accordingly requires pertinent expertise. Sas and Neustaedter (2017) as well sees tinkerable, transparent hardware as a goal for future IoT design, a demand very much aligning with the proposed Right to Improve.

Lastly, the quality of the interactions with current IoT and smart home systems may provide ample motivation towards implementing a Right to Improve, since novel software with improved capabilities would enable users to create automations according to their personal needs, a demand stated by Salovaara et al. (2021). When additional parameters for automation can be taken into account, the reasoning behind a systems decision can be retraced in a comprehensible way, which could in turn increase acceptance of environmentally friendly (Casado-Mansilla et al., 2019) or other automations (Offermans et al., 2013). Centralizing control was also stated as a core desire of users by Brush et al. (2011), which is currently almost impossible to achieve unless users are outfitting their homes with appliances produced by one singular manufacturer conglomerate which does cooperate with the user's chosen interaction platform (e.g., Home Assistant, Apple HomeKit, Google Home).

4.3 Gaps in the academic and technical state of the art

As shown above, the literature contains technical and motivational foundations that align with the Right to Improve. However, the State of the Art is limited in terms of aim and reach in comparison to a decidedly consumer-oriented, authoritative (future) law. (This should not be read as a per-se criticism of the retrieved papers: they just happened to focus on other topics instead.) It goes without saying that our interpretation also discusses the absence of evidence only, i.e., our research yielded preciously few results that directly and positively support our view in this regard. It does not rule out their possible existence in principle.

4.3.1 Changing the state of the art in COTS hardware is not in focus

While providing valuable input towards future design principles, the analyzed publications seldom address the current situation concerning the design of COTS devices in a constructive manner. Some try to work around the limitations using kit-based approaches, which require more in-depth knowledge or facilitation to apply and more often than not lead to unsustainable or aesthetically unsatisfying results. Others solve just the particular given problems by way of a prototype with no wide applicability or prospect of generalizing towards other use cases. There are solutions directed entirely at the IIoT, a sector where highly specialized made-to-order machinery is deployed instead of COTS devices. Lastly, while targeting the application of COTS devices, novel middleware solutions do not aim to improve their general design but work around the limitations imposed by the design decisions made by hardware manufacturers.

4.3.2 Working for consumers is not in focus

Oftentimes the target of the results presented in the analyzed publications is not necessarily aimed at improving the situation for consumers but other audiences instead, such as teachers or expert users. Most highly technical solutions are designed to help experts decide on what technology to use or facilitate the design and deployment of complex, heterogeneous IoT systems in large-scale environments. The same observation can be made for another class of experts: Teachers. Plenty publications mention the importance of pedagogic IoT applications in order to inspire and engage young people with the IoT. This admittedly may improve the situation for consumers in the far future, however, it is not the direct goal of the publicized work.

4.3.3 Interoperability initiatives have had only moderate success

The existence of interoperability initiatives by the industry and by standardization bodies generally demonstrates some awareness of the problem of vendor lock-in in IoT devices. However, voluntary initiatives (as opposed to mandatory laws) suffer from participation dynamics. As long as the initiative is small, it is toothless anyway, and there is little point in joining it, particularly for oligopolists with a large installed base. If the initiative has substantial backing, but doubts on its usefulness arise, this might lead to a negative spiral. The Matter initiative is currently fearing such dynamics after manufacturer Belkin decided to (at least) postpone its support for Matter[3].

4.3.4 Legislation as a means of enforcing progress is not in focus

When it comes to implementing sustainable design patterns, the analyzed scientific literature mainly tries to convince manufacturers with novel, more sustainable ideas for shaping the future of IoT products instead of enforcement via legislation. Since shareholder value and profit margins tend to be more important goals for corporations, such proposals rarely come to fruition. Even though some papers call for researchers to engage in the political debate concerning viable infrastructure for making, few concrete tangible demands towards legislatively ensuring improving are made.

4.4 Summary

We proceed to summarize our findings. To reiterate, we envision that a Right to Improve should be formulated and implemented to give consumers the right to augment and re-purpose their devices in an open-ended fashion during its productive lifetime. This also facilitates overcoming one of the most unnecessary causes for premature obsolescence of IoT devices: loss of connectivity or cancellation of service provision by manufacturers. The Right to Improve aims to achieve this by prescribing open interfaces on devices, making it possible for users and manufacturers (including third-party ones) to connect to devices and freely use them

3 https://www.theverge.com/2023/3/15/23641930/belkin-matter-wemo-smart-home, visited 05/18/2023.

independent from the manufacturer's app or user interface modalities and capabilities, thus increasing the resilience of IoT devices and their adaptability to challenges present and future, be they problems with security, connectivity, or interoperability.

The higher goal, i.e., providing the ability to modify and improve on devices, is congruent with findings from the academic literature that inquires user demand and desires. It is also consistent with what can be achieved with current technology, which however is limited to experts (rather than the general public) and prototypes (rather than Commercial Off-The-Shelf hardware).

Interoperability initiatives from the industry have so far failed to reach that goal, and the existing European Union legislation does not provide the required reach: It either ignores software issues and the use phase of the device (as is the case with Ecodesign Directive), is limited to a short timeframe after the sale (Sale of Goods Directive), or focuses on the device () and currently overlooks IoT devices altogether. However, given their nature, these laws are effective for European Union consumers and the industry alike, and function even beyond the borders of the European Union by forcing vendors abroad to comply in order to be allowed to sell in the European Union, thus also benefiting non-European Union consumers.

Therefore, we argue that a new law (tentatively called "Right to Improve") should be created that possesses the power to actually change the State of the Art for the better, lastingly, to enable the consumer and help save the environment. Whether the approach indicated above is indeed feasible, and how various interests come into play when aiming for a concrete formulation of the Right to Improve, is subject of the next section.

5 Open problems

Our paper so far tries to present the vision of a Right to Improve and lay foundations for it, argues what speaks for its implementation, and hints at its possible overall direction. However, we leave open a large number of problems that require careful assessment and consideration before a Right to Improve could ever stand the chance of being implemented. We cannot hope to address all possible questions here, but this section attempts to anticipate some of them. We proceed from more detailed questions regarding a potential future law itself, to questions arising in its greater context.

5.1 Scope

5.1.1 Should the Right to Improve only affect IoT devices?

In this paper we focus on the case of IoT devices because we think that they make the most explicit, obvious case for showing the deficits of the current State of the Art, the benefits for a Right to Improve that frees them from these limitations, and the already existing ways and methods for actually improving devices. Nevertheless, we think that a Right to Improve could apply to other types of devices as well. Concrete inclusion and exclusion criteria (e.g., Is the device "smart," regardless of its product category? Does malfunctioning of the device result in safety hazards?) and resulting reasonable extents for the Right to Improve must be discussed carefully.

5.1.2 Which extent of openness of interfacing should the Right to Improve prescribe?

One possible interpretation of the Right to Improve is a right to open interfaces–freely documented, probably self-describing ones–that are at least as capable as those used by the manufacturer's modules. One useful starting point would be a simple, physically accessible digital bus that allows accessing all of the device's user interface functions and couple them with a (local home automation) network bus of one's choosing. Another option could be a high-level RESTful API for every function that the device performs, assuming the device has some kind of digital/networked interface to begin with. The extent of these interfaces, and whether they comprise software, hardware, or both, is different for different device categories, and requires individual treatment. We present a prototypical solution with SerIoT in our recently published work (Lebloch and Rafetseder, 2023).

5.2 Challenges

5.2.1 How will the Right to Improve impact intellectual property and market leadership?

If implemented as a merely standardized way to access user interface functions, it is hard to see any amount of intellectual property at risk through opening up access. Even going as far as opening up internal electrical buses might border on triviality in terms of obviousness, at least for a skilled person. In terms of markets, we envision that new dynamics are possible by allowing third parties to compete on user interfaces, automation, and orchestration with new qualities not considered by the original manufacturer. Either way, standard market protection schemes may be employed, e.g., grandfathering, or exemptions below certain product volume thresholds.

5.2.2 How will the Right to Improve affect the security and safety of devices?

Clearly, access granted through the Right to Improve must not render devices unsafe or dangerous–an interface equal in function to the already existing physical interfaces is about as safe (or unsafe) as that physical interface. The question of security is on the manufacturer in either case, as they are responsible for the device firmware (and generally have an unfortunate track record when it comes to maintaining and updating it). If the access to the device is extended to the public Internet, and a large number of appliances can be controlled by an attacker, Distributed Denial of Service attacks on power grids or similar critical infrastructure become possible. Future discussions about locally operated, cloud-controlled, or hybrid devices would need to take the Right to Improve into account as a potential vector.

5.3 Legislative process

5.3.1 Should the Right to Improve become right or an obligation?

We think that a Right to Improve should entitle consumers to an open interface to their devices (as the Right to Repair entitles them to repair). This leaves some leeway for manufacturers of devices to implement the required interfaces, but places no *a priori* burden on stakeholders other than the manufacturer to solve the problem. An alternative approach (modeled on the Ecodesign Directive) could prescribe certain requirements to be met by the manufacturer already during the design phase and build specific open interfaces into the devices right from the onset.

5.3.2 Who are the stakeholders to formulate a Right to Improve?

As we show in our literature review, the industry players do understand interoperability as a problem, and suggest own proposals to tackle it. They also possess the insight into markets, device cost structures, OPEX for cloud services, and other relevant economic data on the supply side. On the other hand, end users and consumers are aware of device capabilities and have creative views of what goals to achieve with their devices–examples of this (through the lense of academic Computer Science) our paper cites as well. It is clear that a balance must be found between these positions on corporate and consumer freedom, and, even more importantly, societal and environmental interests. For this, legally enforceable compliance (up to exclusion from the market) can be a necessary tool.

6 Conclusion

This paper presents the vision of a "Right to Improve," a hypothetical future law that ensures adaptability, augmentability, and open-ended repurposing of devices during their use phase by consumers. A Right to Improve could help to avoid the premature End of Life for strictly cloud-dependent devices, and also enable unforeseen, new ways for users to appropriate their devices and adapt them to their own taste and requirements.

The contribution of this paper is to summarize relevant legislation and literature, point out both gaps and evidence for the utility and feasibility of a Right to Improve, and thus contribute to the foundations of an informed discussion in the creation of such a regulatory tool.

We base our argument for the Right to Improve on two points. We first summarize the relevant European Union legislation in the field (§2): The Ecodesign Directive, the Sale of Goods Directive, and the recently published Right to Repair. Then, we review academic literature on IoT technology (§3) as a representative class of devices. Our analysis (§4) shows that the current legislation has a different focus, has gaps in its extent and lifespan, or is not applicable during the use phase. Despite its nominally limited geographical reach, it is powerful even in non-European Union territories. The literature evidences that modifications to IoT devices are both technically feasible and also desired by users. However, research has mostly fallen short of targeting Commercial Off-The-Shelf (COTS) hardware (instead of prototypes) or non-expert users. Industry interoperability initiatives have failed to progress in this direction as well.

We argue that a Right to Improve should be created as new regulation that overcomes these limitations and makes it possible for users to improve their IoT (and possibly non-IoT) devices not only at the discretion of the manufacturer, but per default. This situation can be created by establishing a Right to Improve as statutory law.

While our paper lays the foundations and motivates that a Right to Improve should and will be developed, we can only scratch the surface in terms of its potential concretion, and suggest but selected few open problems (§5). Further research in different directions, including economic, legal, security, and actual technical implementation details is needed to balance the various interests before a reasonable new regulation can be implemented.

Author contributions

KL: Writing–original draft, Writing–review and editing. AR: Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

The authors thank Paul Fuxjäger for suggesting the regulatory perspective, and Christian Löw and Florian Metzger for discussions on an earlier draft of this paper. The first author received support from the University of Vienna Doctoral School Computer Science (DoCS).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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