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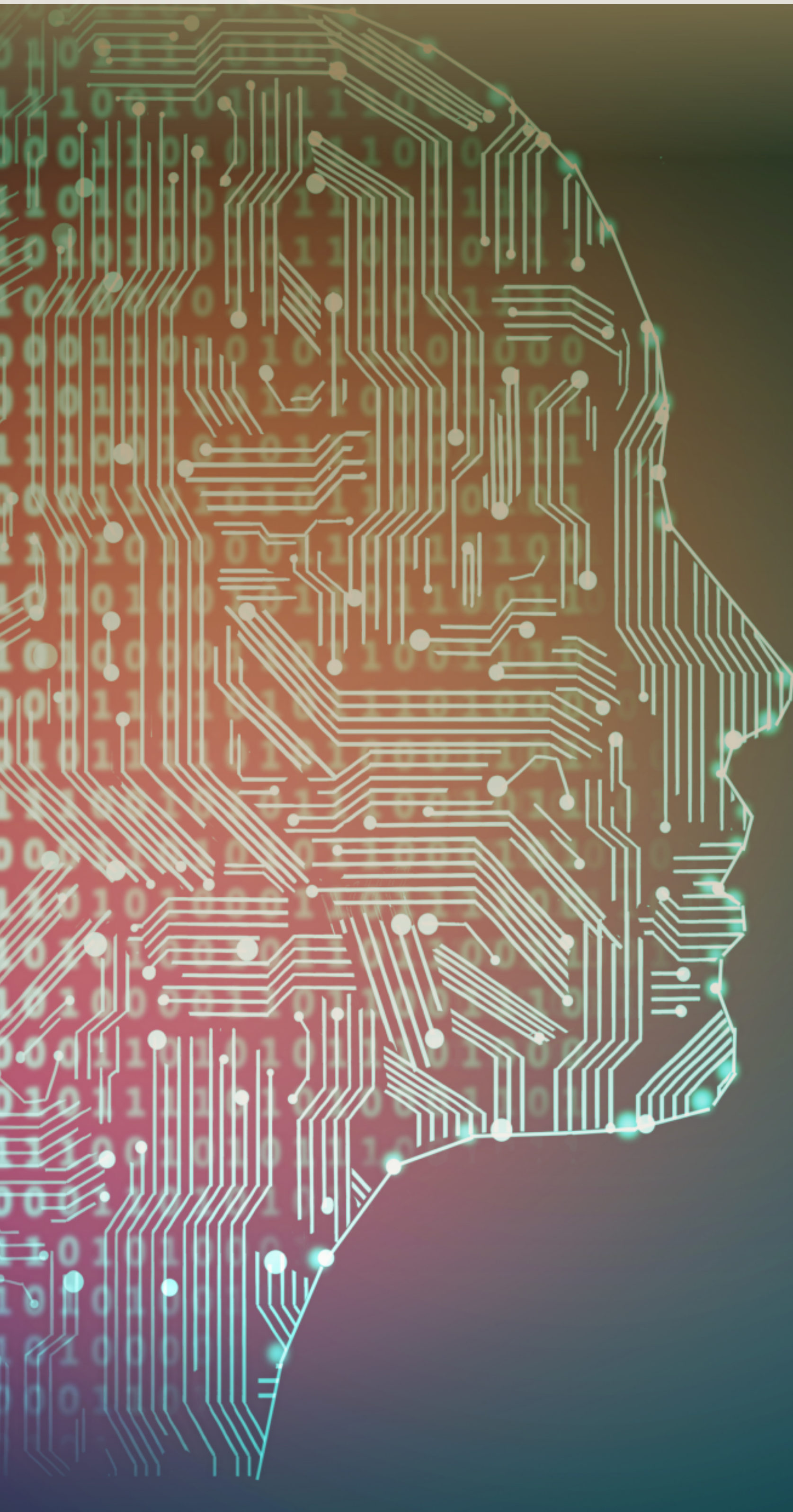

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Índice

Table of Contents

TECHNO Review | Vol. 9, No. 2, 2020 | ISSN 2695-9933
International Technology Science and Society Review / Revista Internacional de Tecnología Ciencia y Sociedad
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ANTROPOLOGÍA ESTÉTICA EN EL TECNOCENO

Epistemología y nihilismo

Aesthetic Anthropology in the Technocene: Epistemology & Nihilism

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KEY WORDS

Epistemology
Posthumanism
Anthropocene
Technocene
Aesthetic Anthropology
Technique
Nihilism

ABSTRACT

The transformation of nature operated by the technique has given rise to a new epoch, the Technocene. To understand how technology dominates our societies, it is necessary to explore the foundations of modern epistemology. Faced with this nihilistic and technological epoch, an aesthetic anthropology arises as an alternative to establish a new difference capable of compensate the dominance of the technique. Thus, different practices are discovered, languages that do not reduce the world to calculation and measurement; a clearing that allows the recovery of what is properly human in a world that is entering a posthuman era.

PALABRAS CLAVE

Epistemología
Posthumanismo
Antropoceno
Tecnoceno
Antropología estética
Técnica
Nihilismo

RESUMEN

La transformación de la naturaleza operada por la técnica ha dado lugar a una nueva era, el Tecnoceno. Para comprender cómo la tecnología domina nuestras sociedades es necesario estudiar los fundamentos de la epistemología moderna. Frente a esta época nihilista y tecnológica, una antropología estética surge como alternativa para establecer una nueva diferencia capaz de compensar el dominio de la técnica. Se descubren así prácticas distintas, lenguajes que no reducen el mundo a cálculo y medida; una apertura que permite recuperar lo propiamente humano en un mundo que se adentra en lo posthumano.

GLOBAL KNOWLEDGE ACADEMICS

Introducción

La transformación del medio ambiente operada por la actividad humana ha dado lugar a una nueva era geológica, el Antropoceno. Sin embargo, dicho concepto ha sido redefinido de diferentes formas. De entre todas esas redefiniciones, el Antropoceno cultural permite analizar esta era como un proceso de transformación cuyos fundamentos responden a transformaciones epistemológicas. Dichas transformaciones epistemológicas han hecho de la tecnología un motor de cambio industrial, económico y social. Esto nos lleva a una reformulación del Antropoceno en términos tecnológicos, el Tecnoceno. Dichos cambios no se limitan a las transformaciones industriales, económicas y ambientales, sino que afectan a la propia subjetividad humana en su sentido más profundo. El Tecnoceno es la era de la superación de lo humano por la técnica, el advenimiento del posthumanismo tecnológico (Tirosh-Samuelson, 2012).

La revolución científica de la modernidad separó las cualidades primarias, objetivas, de las cualidades secundarias, subjetivas. Las primeras permitieron reducir el mundo a unidades de medida y cálculo. Las segundas, no susceptibles de cálculo matemático —por volátiles, indefinidas y relacionales— fueron resguardadas en la oscura esfera de la subjetividad. El proyecto moderno y su modelo de sujeto agrietó la subjetividad humana, degradando los aspectos estéticos. Sin embargo, esta concepción permitió importantes transformaciones científicas y tecnológicas. La lógica moderna se separó de la lógica antigua, estableciéndose los fundamentos para el desarrollo del software y el hardware. Las transformaciones tecnológicas dieron lugar a diferentes revoluciones industriales. Nos encontraríamos en el comienzo de la Cuarta Revolución Industrial, una nueva era tecnológica caracterizada por tecnologías como la inteligencia artificial (IA), el internet de las cosas (IoT) o el big data, entre muchas otras. Dichas tecnologías no solo transforman la producción, la economía y las relaciones sociales, sino que pueden llegar a afectar al ser humano en sus aspectos esenciales.

Frente a todo este proceso científico y tecnológico, se hace necesario prestar atención a los aspectos humanos que no fueron reconocidos por esta concepción moderna, es decir, prestar atención a las denominadas cualidades secundarias y sus aspectos relacionales. El pensamiento estético, una ciencia menor, se postula como posible salida al dominio absoluto de la técnica. El Tecnoceno es la era del nihilismo consumado —la técnica por la técnica— donde lo humano queda ensombrecido e incluso "avergonzado" (Anders, 2011: 187). En contraposición, se propone como solución complementaria a la técnica el desarrollo de lo estético, el cultivo de los aspectos considerados secundarios para la forja de verdaderos vínculos sociales. Lo estético, como acontecimiento que sucede entre el ser humano y el mundo, desvela su verdad; el cuerpo —inteligencia encarnada— y el afecto —la forja de vínculos reales— como sustrato del desarrollo humano. Finalmente, a través de un pensamiento estético sucede o acontece la apertura al ser, más allá de lo medible y representable: apertura de sentido en un mundo de cálculo y computación que parece haber perdido su mesura.

1. Antropoceno epistémico o Tecnoceno

Los geólogos establecen divisiones de la escala temporal geológica según los cambios marcados en el estado de la Tierra. Los recientes cambios ambientales globales sugieren que la Tierra puede haber entrado en una nueva época geológica dominada por el hombre, el Antropoceno. El término Antropoceno fue acuñado por Crutzen y Stroemer (2000) por considerarlo apropiado para enfatizar el rol central de la humanidad en la transformación ecológica y geológica[1]. La "Geología de la

[1] "Considering these and many other major and still growing impacts of human activities on earth and atmosphere, and at all, including global, scales, it seems to us more than appropriate to emphasize the central role of mankind in geology and ecology by proposing to use the term "anthropocene" for the current geological epoch. The impacts of current human activities will continue over long periods. According to a study by Berger and Loutre (14), because of the anthropogenic emissions of CO2, climate may depart significantly from natural behaviour over the next 50,000 years. To assign a more specific date to the onset of the "anthropocene" seems somewhat arbitrary, but we propose the latter part of the 18th century, although we are aware that alternative proposals can

Humanidad" (Crutzen, 2002) comenzó con la Revolución industrial a finales del siglo XVIII pero, desde mediados de siglo XX, la intensidad de la actividad humana sobre el planeta se ha incrementado notablemente. Desde los años cincuenta del siglo XX se ha producido una "gran aceleración", marcada por una importante expansión de la población humana, grandes cambios en los procesos naturales y el desarrollo de nuevos materiales, desde minerales y plásticos hasta contaminantes orgánicos biopersistentes (Lewis y Maslin, 2015). Para Zalasiewicz (2008), los impactos de la actividad humana —la causa más importante de la transformación del medio ambiente—, serán observables en el registro estratigráfico geológico durante millones de años.

El cambio climático de origen antropogénico está produciendo, entre otros muchos fenómenos, el calentamiento de lagos, ríos y océanos (Rosenzweig et al., 2008). La transformación de la tierra para la producción de alimentos, combustibles o materias primas esta provocando que la ratio de extinción sea hasta 100 veces mayor que la tasa natural. Las estimaciones revelan una pérdida de biodiversidad excepcionalmente rápida en los últimos siglos, lo que indica que ya se está produciendo una sexta extinción masiva (Ceballos et al., 2015). Algunas investigaciones atribuyen todo este proceso al extraordinario consumo de energía llevado a cabo por la actividad productiva humana desde 1850 (Syvitski et al., 2020), causante de cambios estructurales en la superficie terrestre (Overpeck y Udall, 2010) y la masa forestal (Huang, Anderegg y Asner, 2019). Los datos de los que disponemos permiten afirmar que el Antropoceno es la nueva era geológica operada por la actividad humana que sustituye al Holoceno: el ser humano se ha convertido en una fuerza geológica (Steffen, Grinevald, Crutzen, & McNeill, 2011).

El concepto de Antropoceno ha sido objeto de diversas reformulaciones. Para Jason Moore (2017) la definición de Antropoceno implica imputar una responsabilidad a una totalidad, los seres humanos, cuando en realidad sería un problema creado por una particularidad, el capitalismo. La responsabilidad "antropogénica" oscurecería la responsabilidad "capitalogénica" de la crisis ecológica. Para Moore, el concepto de correcto sería el Capitaloceno. Otros autores como Bonneuil y Fressoz (2016), abordan diferentes "cenos", conectados entre sí, como el Termoceno —historia del complejo industrial del carbono que les lleva a identificar un Angloceno—, el Tanatoceno —la historia natural de la destrucción a través de la guerra y el ecocidio— o el Fagoceno —que aborda la era del consumo de masas—.

Este trabajo entiende que, para comprender en profundidad la genealogía de esta nueva era geológica, hay que adentrarse en sus fundamentos epistemológicos, es decir, estudiar las condiciones de posibilidad del Antropoceno. Para ello es necesario desplazarse del Antropoceno geológico al Antropoceno cultural. Siguiendo a Donna Haraway, Trischler (2016) afirma que el Antropoceno está siendo analizado críticamente por politólogos, antropólogos, sociólogos, economistas, filósofos y, por supuesto, historiadores. El Antropoceno cultural implica una intersección de disciplinas que dibuja un espacio para el estudio de la historia de la epistemología moderna como condición de posibilidad de esta nueva era geológica.

Dentro de la cultura de la modernidad, un determinado enfoque epistemológico ha sido dominante. La reducción del mundo a cálculo, magnitud y medida hace del Antropoceno un Antropoceno "epistémico". Durante la Modernidad, la distinción entre cualidades primarias y secundarias declaró que solo las primeras —susceptibles de cuantificación y expresión matemática— son cualidades intrínsecas de las cosas, es decir, objetivas. Si para Aristóteles era imposible matematizar la cualidad, el pensamiento galileano y cartesiano, incapaz de explicarla, la abandonó, "atribuyéndola a la subjetividad" (Koyré, 1990: 276). La epistemología moderna, con su nuevo método, dio lugar a una nueva realidad. Los elementos que no encajaron en ese esquema fueron declarados subjetivos. La subjetividad fue el receptáculo contenedor de elementos incómodos e irracionales, inútiles para la medida, el cálculo y la

be made (some may even want to include the entire holocene). However, we choose this date because, during the past two centuries, the global effects of human activities have become clearly noticeable" (Crutzen y Stoermer, 2000: 17) precisión. El espacio definido por una epistemología fundamentada en cualidades primarias, el espacio "epistémico", devaluó la esfera de elementos no acomodables a lo epistémico, el espacio relacional o "estético".

El Antropoceno epistémico sentaría las bases de un Antropoceno tecnológico o *Tecnoceno*. Para Augusto Cera (2017: 244), el Antropoceno "describes only the surface character of an epochal phenomenon which, in its true sense, should be named "Technocene" since technology represents here and now the only possible "subject of history" and the same goes for nature". Igualmente, para Alf Hornborg (2015: 62) "rather than imply that climate change is the inexorable consequence of the emergence of Homo Sapiens, as suggested by the notion of the Anthropocene, I would thus prefer that the geological epoch inaugurated in the late eighteenth century be named the Technocene". Este enfoque permite focalizar la atención en una determinada versión del sujeto humano; un sujeto que pule el espejo de la representación para reducir la realidad a cualidades primarias, unidades de medida, cálculo y computación. El giro epistemológico de la modernidad y el dominio de la técnica serían los determinantes del Antropoceno epistémico o Tecnoceno. La técnica instrumentaliza todo, incluido al ser humano, "la técnica impone el modo de ser de las cosas. La técnica es el ser mismo" (Baltar, 2020: 24-25).

2. Genealogía del Antropoceno epistémico

2.1. De la ontología a la epistemología, de la epistemología a la computación

Siguiendo Hottois (1999), podemos afirmar que la ciencia antigua era logoteórica, contemplativa y posible gracias al lenguaje natural. El conocimiento antiguo era ontológico, su misión esencial era conocer la estructura fundamental de la realidad. Las estructuras esenciales del mundo eran expresadas por el lenguaje natural, es decir, un lenguaje no formal ni matemático. La imagen simbólica que ofrece el lenguaje natural es verdadera cuando es perfectamente adecuada a la realidad. El conocimiento consistía en descubrir la correcta articulación de las palabras que permite su correspondencia con las estructuras esenciales de la realidad, el mundo tal y como es en sí mismo. Por el contrario, la ciencia moderna "partirá del principio de que el saber de naturaleza verbal y tradicional no es fiable" (Hottois, 1999: 27).

La filosofía es ontología, la aspiración a un conocimiento puro y absoluto, pues "sólo la filosofía puede ocuparse de esas cuestiones y tomar una actitud verdaderamente crítica frente a la validez de los fundamentos de la ciencia y de sus mismos fundamentos" (Tomar, 2000: 244). Mientras que la filosofía "es propiamente 'ontológica' porque focaliza su reflexión sobre el ser mismo, o el ser en cuanto ser" (Grondin, 2006: 27), las ciencias particulares se mueven en un plano óntico. La filosofía interroga sobre lo fundamental, cuestión que no ocupa a las ciencias particulares o experimentales. El olvido del ser, el nihilismo, borra la diferencia óntico-ontológica, dejando a las ciencias particulares en un plano único, absoluto. Las ciencias aplicadas hacen de la técnica el único sujeto de la historia.

El proyecto de la modernidad alteró la comprensión ontológica del conocimiento. La revolución científica del siglo XVII modificó la forma en que había sido concebida la materia previamente. La física matemática rompió con la lógica aristotélica, "la naturaleza no responde más que a las preguntas formuladas en lenguaje matemático, porque la naturaleza es el reino de la mediada y el orden" (Koyré, 1990: 147). Como resultado de los trabajos de Galileo y Descartes, entre otros, se introdujo una concepción mecanicista de la materia; ésta encuentra entre sus atributos la extensión y la localización en el espacio y el tiempo. La nueva mecánica no busca la esencia del movimiento sino sus propiedades susceptibles de tratamiento matemático, es decir, la nueva mecánica es una teoría matemática del movimiento.

Para Husserl, "el proyecto físico-matemático de la ciencia moderna realiza el sueño antiguo y legítimo de la razón, pero con una grave amputación. Bajo la forma de la ciencia moderna, el saber racional se hace unilateral no conoce más que el objeto, la naturaleza, la cantidad" (Hottois, 1999: 256). La comprensión científica de la modernidad, útil para ciertos fines de medición y cuantificación carecería de conceptos para estudiar el ser. Husserl "consideró acertadamente que la cientificidad de la filosofía no puede estar motivada por la utilización del método experimental o del método matemático, ya que la filosofía se engloba en un orden distinto y superior al de las ciencias naturales y matemáticas" (Tomar, 2000: 253-254). La ciencia moderna reduce el mundo a magnitud, no conoce más que las denominadas "cualidades primarias", que trata de volver ontológicas. De esta forma, la ciencia moderna inaugura, de forma subrepticia, un proyecto metafísico nuevo, una nueva metafísica bajo el disfraz de una nueva física-matemática. La epistemología moderna como teoría científica de la realidad ontológica.

Con estos antecedentes es necesario estudiar la transformación en el orden del conocimiento que ha borrado la diferencia ontológica y que ha hecho posible el Antropoceno epistémico o Tecnoceno. La epistemología moderna sustituye, metafóricamente, la esencia de vidrio aristotélica por el espejo de la naturaleza cartesiano. Para Rorty (2010: 50), el sujeto cartesiano-lockeano "examina entidades que tienen como modelo a las imágenes de la retina". El examen de ideas entendidas como representaciones en el espejo de la mente no habría tenido equivalente dentro de las tradiciones griega y medieval. Imaginar la mente separada del cuerpo era un "proyecto totalmente diferente del que se encuentra en la tradición procedente de Aristóteles" (2010: 56). Ese nuevo espacio mental separado es el espacio de la indubitabilidad, una noción distinta a la eternidad platónica:

> El cambio cartesiano de la mente-como-razón a la mente-como-escenario-interno no fue tanto el triunfo del arrogante sujeto individual liberado de las trabas escolásticas cuanto el triunfo de la búsqueda de certeza sobre la búsqueda de sabiduría. De ese momento en adelante, quedaba abierto el camino para que los filósofos consiguieran el rigor del matemático o del físico matemático, o explicaran la apariencia de rigor en esos campos, en vez de tratar de ayudar al hombre a conseguir la paz mental. La filosofía se ocupó de la ciencia, más que de la vida, y su centro fue la epistemología. (2010: 64)

La revolucionaria ciencia moderna rompió con el antiguo modelo aristotélico-escolástico que consideraba que "our everyday experience are real qualities of bodies" (Nolan, 2011: 8). La revolución científica "produced a novel conception of matter according to which matter was radically different from the way in which it had been conceived of previously" (Priest, 1989: 32). El nuevo proyecto científico de la modernidad "restricted the 'real qualities' of bodies to those can be understood in mechanical or geometric terms, and treated qualities such as sensuous red as mere appearances" (Nolan, 2011: 1). El resto de cualidades fueron consideradas meras apariencias subjetivas derivadas de cualidades primarias, que no pueden ser utilizadas en la explicación científica de los fenómenos naturales. Desde entonces, la estética, ciencia de la sensibilidad —una disciplina menor—, se ocupará de ese terreno oscuro "en contraste con el terreno más espiritualizado del pensamiento conceptual" (Eagleton, 2006: 65).

El núcleo central de la argumentación afirma "there are certain qualities that objects in the world have intrinsically, independent of our perception of them, while there are others that we ascribe to objects only in relation to our perceptual apparatus or sensibility" (Nolan, 2011: 3). Las cualidades primarias —extensión, forma, tamaño, posición, movimiento— son objetivas, intrínsecas y no relacionales, es decir, tienen correspondencia con la realidad tal y como es en sí misma. Las cualidades secundarias —color, olor, sensaciones táctiles, dolor—, relacionales, son producidas por el impacto de las cualidades primarias sobre el observador y, por tanto, subjetivas —se experimentan gracias al observador—.

En base a esta distinción moderna podemos distinguir entre cualidades humanas y no humanas, siendo las primeras afectivas y las segundas neutrales y asépticas, objetivas. El nuevo proyecto científico restringe las cualidades reales de los cuerpos a aquellas que pueden ser comprendidas en términos mecánicos o geométricos. Desde entonces, "lo subjetivo va asociado a emocional o fantástico, pues nuestros corazones y nuestras imaginaciones son idiosincrásicos, mientas que nuestros entendimientos son, en sus mejores momentos, espejo idéntico de los objetos externos mismos"

(Rorty, 2010: 307). Las cualidades primarias nos ofrecen información objetiva sobre el mundo exterior mientras que las cualidades secundarias solo existen en nuestra percepción. Llevando el argumento al extremo, podemos afirmar que solo existen en nuestra imaginación, sin correspondencia real pues "ni el color, ni el olor, ni el gusto, ni las sensaciones táctiles poseen formas que puedan ser analizadas, pues son sensaciones difusas, vagas, sin estructura" (Tafalla, 2019: 78). Las sensaciones personales son difícilmente determinables por su carácter indefinido y volátil, difícilmente reducible a unidades idénticas, unidades de lo mismo que permiten el cálculo. Son singulares, diferenciales y, por tanto, introducen desorden e incomunicabilidad frente a la claridad y universalidad del pensamiento conceptual.

En líneas generales, este proyecto epistemológico se encuentra explícito en los trabajos de Locke y Boyle, pero diferentes versiones de se encuentran en Galileo, Hobbes, Descartes, Spinoza, Newton, Leibniz o Kant. Para Descartes, solo conocemos los objetos en términos matemáticos; las únicas ideas claras y distintas son las ideas matemáticas, además de ciertas proposiciones lógicas. Las cualidades secundarias son oscuras y confusas, y no son válidas para operaciones matemáticas (Burtt, 2003). El rechazo de Descartes de la noción escolástica de sustancia, no reducible a los términos cuantitativos, hace de las propiedades geométricas de la materia componentes suficientes para la descripción científica del mundo: "Descartes' mechanism and the metaphysics of it need to be understood in the light of the rejection of the Scholastic common-sense inspired scientific approach according to which the senses are a reliable source in getting us acquainted with truths about the natural world" (Ortín Nadal, 2019: 3).

La reducción del mundo a magnitud se expresa con claridad en la obra de Thomas Hobbes. Hobbes propuso que el razonamiento era como la computación numérica, "pues la razón no es otra cosa que calcular" (Hobbes, 2004: 46). Al calcular, la razón unifica una variedad, geometrizándose. Frente al conocimiento como búsqueda de las esencias de las cosas —la razón teorética o contemplativa—, "la razón geométrica es más bien instrumental u operativa y repele todo aquello que no pueda conocerse por medio del cálculo" (Branda, 2008: 78). El impulso formalista de la modernidad llevó a Leibniz y Hobbes a "desarrollar un modelo sistemático de pensamiento a base de llevar el mecanicismo al estudio científico de la mente" (Cabañas Agrela, 2010: 72). El lenguaje ideado por Leibniz [2] sería "un lenguaje universal artificial o sistema de escritura internacional legible por todos los ciudadanos de la *République des Lettres*, que resolvería el problema del método asegurando la certeza, pero sin abrumar la mente" (Cabañas Agrela, 2010: 71). Para Leibniz, las cualidades secundarias son particularmente confusas, sin embargo, "primary qualities, by contrast, are intelligible because our concepts of them are innate and because the qualities themselves are common to several sense organs" (Nolan, 2011: 10).

Siguiendo a Kline (1980), a partir del siglo XIX, surge la lógica moderna con contribuciones determinantes. Boole pensó que la simbolización del lenguaje rigorizaría la lógica: las leyes del razonamiento podían ser expresadas de forma simbólica. A través de sus obras —especialmente su *Mathematical Analysis of Logic* (1847) y su *Investigation of the Laws of Thought* (1854)—, trató de construir una ciencia de la lógica que la separaría de la filosofía y la uniría a la matemática. Frege continuará la problemática leibniziana: el desarrollo de una lengua universal para liberarnos de las imperfecciones del lenguaje ordinario. Con *The Fundamental Laws of Arithmetic* (1884), Frege redujo la matemática a la lógica: las definiciones y leyes de la aritmética se derivarían de premisas puramente lógicas. Al expresar los conceptos de la aritmética en

[2] En el siglo XIII la obra de Raimundo Lulio, Ars Magna, planteó construir una máquina lógica de naturaleza mecánica para probar la verdad o falsedad de cualquier postulado introducido. Se trataba de hacer del razonamiento un cálculo lógico automatizado. La idea de una lengua universal, presente en el pensamiento de Lulio, preludia el intento de Leibniz de concebir una mathesis universalis; "el ars magna de Lulio deviene en el ars combinatoria de Leibniz. Solo es otra presentación distinta del mismo ideal" (Beuchot, 2016: 189). Gottfried Leibniz construyó una máquina que podía sumar y restar mediante cilindros rotativos interconectados. En el siglo XIX, Charles Babbage diseñó un motor analítico capaz de todas las operaciones lógicas y aritméticas elementales, y con sus desarrollos anticipó el ordenador digital moderno. Si bien la gran complejidad mecánica de su diseño impidió su construcción, Babbage aportó la idea de programa, como un conjunto de instrucciones que controlan las operaciones de un ordenador (Churchland, 2013).

términos lógicos, la matemática quedó como extensión de la lógica:

> El objetivo final de Frege consistía en reducir la aritmética (y el análisis matemático) a la lógica, definiendo las nociones aritméticas a partir de nociones puramente lógicas, y deduciendo los teoremas de la aritmética a partir de principios lógicos. Como la lógica tradicional no bastaba para llevar a cabo esa tarea, se vio impulsado a crear una nueva lógica, suficientemente precisa, flexible y potente como para poder desarrollar gran parte de la matemática a partir de ella. De hecho, en *Begriffsschrift* aparecen por primera vez, y de golpe, varios de los análisis, conceptos y métodos característicos de la lógica actual. (Mosterín, 2007: 63)

Ya en el siglo XX el proyecto de Russell y Whitehead —los *Principia Mathematica* (1910-1913)—, buscó consolidar la matemática sobre bases lógicas. Trataron de deducir, a partir de un sistema de axiomas —sin ningún axioma específicamente matemático—, las leyes de la lógica. Sin embargo, aunque la reducción logicista y fenomenista —reducción de la matemática a la lógica y reducción de la física a los datos sensibles inmediatos, respectivamente— no fue convincentemente establecida “los métodos usados en su desarrollo —el análisis lógico y la reconstrucción formal— resultaron ser 'extraordinariamente fecundos'” (Mosterín, 2007: 216).

Más allá de la confrontación entre intuicionistas, logicistas y formalistas (Lindström, Palmgren, Segerberg & Stoltenberg-Hansen, 2008), la lógica, entendida como un lenguaje que reduce el pensamiento a un proceso formal de símbolos desprovistos de significado, tuvo consecuencias en el campo de la computación, dotando de fundamentos al diseño del software —el programa de computación almacenable como secuencia de dígitos en la memoria de una computadora—, y el hardware —el soporte material—. Von Newman “introdujo el punto de vista formal y lógico en el diseño de la computación, lo que acabó conduciendo a la concepción del programa (*software*) como algo distinto del soporte material (*hardware*)” (Mosterín, 2007: 276). En la segunda mitad del siglo XX, los avances en electrónica hicieron posible la construcción del ordenador digital. Estas máquinas han permitido la automatización de sistemas formales, superando la barrera que limitó a Babbage y alcanzando formas de cálculo muy poderosas. La computación electrónica empezó con la máquina ENIAC, en 1946. Sin embargo, John von Neumann, con el diseño EDVAC, separó el software del hardware e “introdujo la arquitectura actual de los computadores” (Mosterín, 2007: 276). Al instalarse este tipo de ordenadores en departamentos de universidades y laboratorios de investigación, se creó una necesidad de mayor velocidad, mayor capacidad y mayor fiabilidad que motivó un esfuerzo intensísimo por nuevos dispositivos y el desarrollo de nueva tecnología. El uso de válvulas electrónicas de vacío, como en el caso del ENIAC, dio paso al uso de transistores, que supuso una reducción del tamaño de los circuitos y en el aumento de su fiabilidad. Con la tercera generación de ordenadores aparecen los chips, con ventajas como la reducción del coste de construcción, una mayor fiabilidad, bajo consumo y miniaturización. La cuarta generación corresponde a unos niveles de mayor densidad de integración, el microprocesador: el chip que incluye todos los elementos de la Unidad Central de Proceso (CPU). La digitalización permitió traducir cualquier información a un sistema binario de ceros y unos. Con el sistema digital “hemos empezado a trocear la realidad hasta obtener partículas infinitesimales a cada una de las cuales hemos encadenado una secuencia de ceros y unos. La hemos digitalizado, es decir, transformado en números” (Baricco, 2019: 30). De esta manera, el mundo se vuelve modificable, almacenable, reproducible y transferible por máquinas. Es la Revolución digital, una revolución tecnológica que ha supuesto un cambio radical en la manera de producir, pensar y vivir.

A raíz del diseño de los primeros computadores, Von Neumann y Weiner comenzaron las comparaciones entre computadores y cerebros. El interés de Alan Turing en imitar las funciones del cerebro le llevó a escribir *Computering Machinering and Intelligence* (1950), iniciando la investigación en IA. El nombre y el origen mismo de la IA como nueva disciplina se debe a John McCarthy, que uso ese término por primera vez en 1956 en un seminario en *Darmouth College* junto con Marvin Minsky, Nathaniel Rochester, y Claude Shannon (McCarthy, Minsky, Rochester y Shannon, 2006). La IA es el intento de desarrollar máquinas que, de forma automática, puedan realizar las funciones propias de la inteligencia humana, como aprender, resolver problemas o tomar decisiones (Bellman, 1978). En la actualidad, los defensores de la IA "débil" afirman que la tecnología puede ayudar a los humanos en cada vez más tareas. Sin embargo, son solo máquinas inteligentes sin consciencia, cuya inteligencia se remite al cálculo y la computación, es decir, no tan inteligentes desde un punto de vista humano integral. Se trata de una IA que puede estar sometida a los fines del humanismo, no contra él. Sin embargo, muchos transhumanistas afirman la llegada de una IA "fuerte" (Kurzweil, 2005). Cuando hablamos de IA y sus desarrollos más modernos —*machine learning*, *deep learning*, etc.—, hablamos de máquinas que aprenden y consiguen fines definidos. La intencionalidad en la definición de sus propios fines, que elaboraría sus propios modelos explicativos, es la IA "general" o *hard*. El aumento en las tareas que puede resolver una máquina, ayudando a los humanos, es absolutamente distinto de la definición autónoma de fines. Sin embargo, el diseño de un sistema híbrido es el sueño del transhumanismo:

> Si observamos el mundo de la computación y de la inteligencia artificial con ojos de antropólogo, podremos ver que hay allí una especie de cultura embrionaria basada en el cálculo, la programación, la estadística, la lógica matemática y la formalidad de las reglas. Se trata de la cultura del procesamiento de información, de las representaciones en forma sistemática y ordenada basadas en las matemáticas de Charles Babbage, el álgebra de George Boole y el mundo de Alan Turing. Es el universo de lo computable y de los algoritmos. [...] Leibniz y sus sucesores han soñado con la invención de un sistema híbrido capaz de juntar el mundo inestable de las razones y los símbolos culturales con el mundo ordenado de los signos matemáticos y el cálculo. (Bartra, 2019: 127-129)

El proyecto científico moderno está fundamentado en la teoría de las cualidades primarias, que reduce el cerebro humano a un funcionamiento algorítmico. Roger Bartra (2019: 135) argumenta que para ello es necesario comprender la conciencia humana como "un sistema de información regido por las reglas de la lógica matemática, la cibernética y la computación" pero, a diferencia del lenguaje matemático, "los símbolos en la lengua, la literatura, la música y las artes tienen cualidades que hacen pensar y generan sentimientos, pero no lo hacen de una manera exacta e idéntica en cada persona". Los símbolos del lenguaje humano no pueden ser manejados por el lenguaje computacional, un lenguaje que reduce la realidad a unidades binarias que permiten la computación, es decir, traducir la realidad a la lengua que conocen las máquinas, los números.

2.2 Pensar más allá de la técnica y el cálculo

El pensamiento de Nietzsche ha sido utilizado para rechazar las pretensiones ontológicas y epistemológicas del conocimiento (Habermas, 1999). En la interpretación de Diéguez (2011: 203), "el pensamiento de Nietzsche podría considerarse como un cierto tipo de realismo, pero un realismo que pone el énfasis en el modo en que nuestros esquemas conceptuales distorsionan sistemáticamente la realidad". En este sentido, Nietzsche adopta como normativa "una idea de verdad ontológica, esencial que, por haber sido concebida a partir de los criterios fundamentalistas de la tradición metafísica, excluye precisamente su aprehensión por la ciencia, condenada irremisiblemente al plano de lo óntico-fenoménico inesencial" (Romero Cuevas, 2004: 262). En Nietzsche, el mecanismo del conocimiento científico es una proyección humana que nos impediría alcanzar la realidad por tres razones básicas:

> (1) it expresses abstract and simplifying assumptions of identity and deletes the diversity and complexity of immediate experience, (2) it employs metaphor and anthropomorphism that yield a humanized picture of actuality that transforms what is experienced; (3) it is used to describe 'appearances' or constructs that are constituted by our psychophysical

> 'organization' and, hence, cannot describe things-in-themselves. (Stack, 2005: 2)

Para Nietzsche, el pensamiento de la representación —el pensamiento del ser—, niega el devenir pues "lo que es no deviene; lo que deviene no es" (Nietzsche, 2004: 51). Nietzsche trata de recuperar el cuerpo y el espacio sensitivo, opacado por el pensamiento abstracto y conceptual, pues "mostrando el devenir, el perecer, el cambio, los sentidos no mienten" (2004: 53). En *Sobre verdad y mentira en sentido extramoral*, Nietzsche pone de relieve el carácter metafórico del conocimiento, considerándolo una actividad estética. El ser humano debe inventar conceptos para sobrevivir, pero en nada se parecen sus productos a la naturaleza, pues el conocimiento es "niebla cegadora colocada sobre los ojos y los sentidos de los hombres" (Nietzsche, 2010: 23). Para Nietzsche, la naturaleza no conoce formas ni conceptos, es "solamente una x que es para nosotros inaccesible e indefinible" (2010: 28). El ficcionalismo de Nietzsche no deposita el fundamento del conocimiento en la lógica, sino en la imaginación y en la creación de analogías por parte de un sujeto artista y creador al servicio de la conservación de la vida:

> Creemos saber algo de las cosas mismas cuando hablamos [...] Sin embargo, no poseemos más que metáforas de las cosas que no se corresponden en absoluto con las esencias primitivas [...] Todo concepto se forma por equiparación de casos no iguales [...] El concepto hoja se ha formado al abandonar de manera arbitraria esas diferencias individuales, al olvidar las notas distintivas, con lo cual se suscita entonces la representación, como si en la naturaleza hubiese algo separado de las hojas que fuese la hoja. (2010: 27)

El pensamiento de la representación se propone cruzar el abismo entre sujeto y objeto puliendo el espejo de la mente para encontrar las ideas claras y distintas que tienen correspondencia con la realidad —las cualidades primarias depuradas de cualidades secundarias. Por el contrario, para Nietzsche, entre sujeto y objeto no hay exactitud alguna o correspondencia sino una conducta estética, que consiste en "un extrapolar alusivo, un traducir balbuciente a un lenguaje completamente extraño, para lo que, en todo caso, se necesita una esfera intermedia y una fuerza mediadora, libres ambas para poetizar e inventar" (2010: 31). La utilidad de los artefactos lingüísticos, el éxito que generan al permitir desenvolvernos en el mundo, nos transmite la sensación de haber alcanzado la realidad ontológica. Una vez producido el artefacto estético, y demostrada su utilidad, olvidamos su carácter artificial, infiriendo de su éxito su fundamento ontológico o metafísico.

El pensamiento de Nietzsche propone desviarnos del proyecto moderno para acceder a un mundo más rico y variado que la fría racionalidad del concepto, el mundo sensible del devenir. El racionalismo de la modernidad nos fuerza "a asignar unidad, identidad, duración, substancia, causa, coseidad, ser" (Nietzsche, 2004: 54), nos hace confundir el mundo de la representación con el mundo verdadero, pero se trata solo de un error útil. El lenguaje de la representación —reducción del mundo a objeto, número y cálculo—, permite el aseguramiento de la vida, pero los conceptos no capturan la totalidad de lo real:

> El hecho de que un juicio sea falso no constituye, en nuestra opinión, una objeción contra ese juicio [...] Se trata de saber en qué medida este juicio sirve para acelerar y mantener la vida, para conservar la especie, para mejorarla incluso. Por principio, nos inclinamos a afirmar que los juicios más falsos (y entre éstos los juicios sintéticos a priori) son para nosotros los más indispensables, que el hombre no podría vivir sin admitir las ficciones de la lógica [...] sin falsear constantemente el mundo introduciendo en él la noción de número hasta el punto de que renunciar a los juicios falsos sería renunciar a la vida, negar la vida. (Nietzsche, 1996: 41)

El método formal y lógico de pensamiento opera igualando elementos al discriminar las diferencias cualitativas. Partiendo de la experiencia, la inteligencia abstracta reduce y simplifica la multiplicidad del campo experiencial produciendo unidades cuantitativas. Para Nietzsche (2004), el pensamiento de la representación reduce el mundo a unidades simples que niegan el cambio, la multiplicidad y el devenir. El lenguaje falsificaría la realidad[3] y el proyecto moderno aceleraría dicha falsificación siendo el sistema binario digital su máxima expresión o consumación. El lenguaje científico aparece como una poderosa herramienta calculadora. El Tecnoceno define la época en la que la capacidad de resolver problemas de las ciencias ónticas —la técnica y la automatización propiciada por la digitalización—, domina la sociedad y la economía, inaugurando una nueva era geológica dominada por la tecnología.

El pensamiento moderno habría suprimido la multiplicidad de la realidad por la seguridad y el control logrado por la lógica de la identidad. En términos heideggerianos, a través de la representación "lo ente llega a la estabilidad como objeto" (Heidegger, 2010: 76). La representación, entendida como abstracción de la experiencia, separa progresivamente al sujeto del mundo y, a su vez, lo convierte en señor del mundo mediante el dominio de sus "cualidades primarias":

> Descartes define el yo como una cosa pensante, que duda, quiere, siente..., a la cual denomina, res cogitans. Por otro lado, identifica a aquello que representa el mundo exterior de los cuerpos como res extensa. La res extensa está determinada, ante todo, por su extensión y movimiento (además por la forma, el tamaño, la cantidad, el lugar y el tiempo). Esta aclaración permite comprender cómo todas estas 'cualidades primarias' permiten que la naturaleza sea concebida cuantitativa y matemáticamente desde la razón. (Buchholtz, 2015: 27)

En su actividad calculadora, el sujeto reduce la multiplicidad del mundo a la unidad del concepto para sus fines de conservación, disolviendo la materialidad estética de la realidad. Lo objetivo, detenido en la representación, permite el "aseguramiento de las existencias por medio del cual el hombre se asegura dichas existencias materiales, corporales, psíquicas y espirituales, pero sólo por mor de su propia seguridad" (Heidegger, 2010: 194). La reducción del mundo a magnitud oculta u oscurece su esencia porque "este asegurar tiene que ser una forma de cálculo, porque sólo la calculabilidad es capaz de garantizarle por adelantado y constantemente su certeza al elemento representador" (2010: 100). Si antes las cosas se daban "libremente y eran percibidas como un contenido de mundo, ahora cada vez se hace más prepotente, rápida y completa la objetividad del dominio técnico sobre la tierra" (217). Para Heidegger, solo es pensamiento el pensamiento del ser, sin embargo, el hombre moderno "se encontraría constantemente representando y no pensando. Desde esta meditación surge un diagnóstico desgarrador respecto de la experiencia del pensar y, por lo tanto, del hombre en la Época Moderna: El hombre se ha erigido como el gran sujeto representador" (Buchholtz, 2015: 27). La certeza de la representación sucede a la sabiduría.

Haciendo uso de la distinción entre cualidades primarias y secundarias se descubre un predominio de las primeras sobre las segundas, el pensamiento calculador y abstractor de diferencias como única vía del pensamiento, es decir, el no pensamiento, la consumación del nihilismo, el olvido del ser. Los pensamientos de Nietzsche y Heidegger permiten identificar el pensamiento calculador que reduce, en última instancia, el mundo a cantidades de medida, a diferencia de un pensamiento abierto a una comprensión cualitativa de la experiencia del mundo. Este proyecto sería continuado hoy día por el mundo STEM —Science, Technology, Engineering and Mathematics—, condición de posibilidad de la Cuarta Revolución Industrial[4]. Este proyecto sería un determinado ejercicio del intelecto humano, el que potencia la reducción

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[3] Es importante no confundir falsificación —el error de Nietzsche— con simplificación; "Nietzsche toma como errores, falsedades o ilusiones lo que siendo menos estrictos podríamos considerar sencillamente como aproximaciones" (Diéguez, 2011: 208). Las simplificaciones —falsificaciones o ilusiones en el lenguaje nietzscheano— son útiles para los propósitos humanos, y su consideración de ficciones sería contradictoria con su éxito efectivo en la supervivencia y el mantenimiento de la vida.

[4] La revolución 4.0 se caracteriza por la existencia de máquinas y sistemas digitales permanentemente interconectados a lo largo del proceso de producción. Los cambios operados por la Industria 4.0 llevarían a periodos cortos en el desarrollo de productos, la individualización de los pedidos, la flexibilidad, la descentralización, y eficiencia de los recursos (Lasi, Fettke, Kemper, Feld & Hoffmann, 2014). Las posibilidades de este nuevo ecosistema se multiplicarían gracias a los avances tecnológicos emergentes en campos como la inteligencia artificial (IA), la robótica, la Internet de las cosas (IoT), el *big data*, el *blockchain*, la computación en nube, los vehículos autónomos, la impresión en 3D, la nanotecnología, la biotecnología, la ciencia de los materiales y el almacenamiento de energía (Brynjolfsson & McAfee, 2014; Fuchs, 2018; Grinin & Grinin, 2020).

de la realidad a sistemas digitales automatizados contenidos en máquinas. La intensificación de esta opción metodológica borra la diferencia ontológica, y la técnica emerge como el único sujeto de la historia. Así ocurre cuando no somos capaces de reconocer que “el cerebro no es como el hardware y la mente el software de las computadoras. La mente no opera mediante reglas algorítmicas basadas en la simbología matemática” (Bartra, 2019: 136). Como consecuencia, el dominio del lenguaje característico del proyecto moderno se volvería total. Muestra de ello es la existencia de espacios cada vez más reducidos para la meditación, el silencio, la devoción y la serenidad; igualmente los espacios naturales quedan progresivamente degradados por las consecuencias ambientales descritas al comienzo de este estudio.

Si bien no puede dejarse de reconocer el éxito del mundo STEM, lo que se cuestiona es su absolutización metodológica, su intento totalizante y la incoherencia de buscar incluso “máquinas sensibles” (2019: 161), cuando la propia opción metodológica opta por las cualidades objetivas, declarando el resto de cualidades como secundarias e inservibles por “estéticas”. El Tecnoceno, en términos heideggerianos, es la era donde el nihilismo se consuma:

> Para Heidegger el nihilismo consiste en el olvido y el abandono del ser, borrando la diferencia ontológica en favor del ente. Este olvido se corresponde con la historia de la metafísica, que ha sentado las bases de la racionalidad vacía, del pensamiento calculador, de la tecnificación omnímoda. El ser se ha visto 'entificado' y, por ende, 'tecnificado'. El abandono del ser es el indicio del nihilismo consumado, la última fase de la metafísica. (Baltar, 2020: 12-13)

3. La estética como alternativa a la técnica

Para Baumgarten, la estética es la ciencia que se ocupa de desarrollar el conocimiento inferior, secundario, el conocimiento sensible (Baumgarten 2007: §1). Lo estético hace referencia al campo de la percepción y la sensación en contraposición con el campo formalizado del pensamiento conceptual. A mediados del siglo XVIII, el término estético distingue lo material de lo inmaterial, las sensaciones y las ideas, “un territorio denso y desbordante más allá de su propio enclave mental, que corre el riesgo de caer por completo fuera de su dominio” (Eagleton, 2006: 65). El discurso estético no está dirigido “a la generalidad abstracta de la inteligencia, sino a la particularidad concreta de la percepción” (Del Valle, 2011: 317). Lo estético tiene un sentido materialista “hace referencia a la vida sensitiva, en contraste con el dominio más espiritualizado del pensamiento conceptual” (Eagleton, 2006: 65). La particularidad y la materialidad produce un discurso atento a las diferencias, donde predominan las metáforas y hay espacio para percepciones menos claras y distintas, como los sentimientos. Lo estético “designa tanto la capacidad de aprehender la realidad a través de los canales de la recepción sensorial como las categorías de la sensibilidad que son activadas en esa recepción” (Maillard, 2017: 14).

En la *Crítica de la Razón Pura*, Kant utilizará el término estética para hacer referencia al estudio de los principios *a priori* de la sensibilidad, es decir, la estética trascendental. Para Kant (2003), la materia del fenómeno, la sensación, solo pueden ser ordenada por algo que no es sensación. Las fuentes empíricas jamás podrán establecer leyes *a priori*, una verdadera ciencia. Con la distinción entre sensibilidad y entendimiento, Kant separa la materia, fuente secundaria de contingencias, de la forma, garantía primaria de identidad y regularidad. En el plano ético, la libertad trascendental permite al sujeto independizarse de la imposición de los impulsos materiales de la sensibilidad. Lo “patológico” —los móviles de la sensibilidad—, no pueden determinar completamente a la voluntad humana (Kant, 2003: 464). En la *Crítica de la razón práctica*, Kant distinguirá entre “contento estético y contento intelectual”, el primero hace referencia a la satisfacción de las inclinaciones, siempre cambiantes y crecientes, mientras que el segundo es imperturbable y no reposa sobre ningún sentimiento particular (Kant, 2009: 231). Con este formalismo se continúa en el plano moral el proyecto anestético iniciado en el plano epistemológico. El cuerpo, irrepresentable en el proyecto kantiano, dará lugar a ética formalista. Como resultado, la formalización de la moral generará una clara esterilización de la complejidad humana. El yo deontológico “fuera y por encima de la situación en la que está razonando [...] no está comprometido con ningún fin particular, ni tiene historia particular, ni pertenece a ninguna comunidad, ni tiene cuerpo" (Young, 1998: 448-449). Si la razón formal se desentiende de los aspectos estéticos, secundarios, la razón estética pone atención en los aspectos indeterminados para darles forma mediante el ejercicio y la práctica. Baumgartern, propondrá el perfeccionamiento de los ejercicios estéticos como práctica para añadir claridad a lo sensible. Siguiendo a Menke (2020: 22):

> El hecho de que las realizaciones sensibles solo puedan ser perfeccionadas por la práctica, el hábito y el uso frecuente conduce más bien al discernimiento del modo específico, diferente del racional, en que lo sensible debe ser concebido como realización a partir de un principio interno y, por ende, como actividad [...] No es una actividad que pueda entenderse como la aplicación de una teoría que el propio agente tenga de antemano acerca de ella.

El pensamiento formalista excluye el cuerpo. Pero, en realidad, lo racional debe entenderse a partir de lo estético, "only on the basis of the aesthetic or obscure that we can gain a clear understanding of rational clarity" (Menke, 2010: 557). La genealogía del sujeto y sus facultades debe entenderse a partir de la indeterminación estética. El vacío de contenido generado por la subjetividad formal llevará Hegel a "estetizar la razón al anclarla en los afectos y deseos del cuerpo" (Eagleton, 2006: 75). Con Hegel, la vida moral queda estilizada desde un plano material no mediante la ley "sino como costumbre, una forma habitual de acción que se convierte en una 'segunda naturaleza'" (2006: 76). Hegel, "no piensa que la filosofía pueda elevarse por encima de las prácticas sociales de su época", es decir, que "no hay normas que no lo sean de una determinada práctica social" (Rorty, 2010: 55). El temple de instintos y pasiones produce formas de subjetividad que pueden articularse precisamente por su elemento estético. Por el contrario, la subjetividad formal generaría individuos aislados cuya conexión con los demás se establece de forma imaginaria a través de una norma universal abstracta. Lo estético permite la formación de comunidades materiales precisamente por la presencia de un contenido material relacional que impacta en el cuerpo. La cohesión social, asentada en lo estético, es mucho más efectiva que la razón formal; el sentimiento facilita la formación de lazos sociales. Frente al rechazo racionalista de la simpatía, la compasión o el interés, los afectos tienen un componente moral; lo estético une a los individuos, "si vivimos en sociedad no es gracias al deber o a la utilidad, sino a una placentera satisfacción de nuestra naturaleza" (Eagleton, 2006: 88-89).

Lo estético "no es un estado sino un acontecimiento, y el acontecimiento estético es un proceso" (Menke, 2020: 67). La razón estética presta atención al acontecer del mundo de la vida, no concibe la realidad como un objeto estático al que nos enfrentamos de manera objetiva gracias a la "distancia metódica"[5]. La razón estética es una razón relacional, relación con uno mismo —pliegue— y relación con los demás. El dualismo moderno, sin embargo, utiliza el modelo de los entes separados —el interior subjetivo y el exterior objetivo—, y busca la explicación de la conexión entre sujeto y mundo a través de una adecuada teoría de la representación, que conecta al sujeto con aspectos primarios o esenciales de la realidad. Pero dicha separación es artificial, ajustada a fines concretos, utilitarios y pragmáticos: resolución de problemas ónticos. En esta nueva comprensión, que depende fundamentalmente de la fenomenología, el sujeto y el objeto, el interior y el exterior, es el resultado de un proceso analítico de diferenciación posterior al estado originario y unitario donde solo hay vida, existencia, facticidad, en definitiva, mundo:

> Fenoménicamente ni me experimento primero a mí mismo y luego experimento al mundo, ni, a la inversa, experimento primero el mundo y luego me experimento a mí mismo, sino que en la experiencia están dadas ambas cosas a la vez en unión indisoluble. (Safranski, 2007: 190)

La vida, "no podemos observarla desde fuera, estamos siempre en medio de ella" (Safranski,

[5] "El método se funda en la distancia del que observa respecto del objeto observado. Ahora bien, ese modelo de la comprensión a distancia, ¿es el realmente adecuado a las ciencias del espíritu? ¿No está el espectador siempre comprometido de alguna manera en esas ciencias? El positivismo científico ha impuesto un modelo único de saber, el del conocimiento metódico, independiente del intérprete" (Grondin, 2008: 71-73).

2007: 145); la acción es la estructura fundamental del *Dasein*, del ser-en-el-mundo (2007: 191). Si el ser-en-el mundo, "sin distancias" (2007: 190), se entrega "al río del tiempo" (2007: 259), el acontecer de la verdad tiene lugar "en la relación del hombre con su propia mismidad y con el mundo" (2007: 260). No hay ninguna verdad independiente del ser humano, la verdad aparece, se presenta, acontece. En el pensamiento hispano encontramos dos claros intentos de expresar en el lenguaje la vivencia. Con la razón poética y la razón estética, María Zambrano y Chantal Maillard —respectivamente, y a pesar de sus diferencias—, son intentos de aunar conocimiento y experiencia, recuperando la unidad escindida por el pensamiento moderno y el lenguaje racional (Nieto, 2015).

4. Recuperando lo humano

Para que el mundo de la vida se convierta en un mundo puramente tecnológico es necesario desfigurar lo humano y reducirlo a magnitud, cálculo y representación. El Tecnoceno es el la era del dominio de las cualidades primarias, donde los aspectos relacionales, sensitivos y emocionales son valiosos en función de su medida y utilidad. En el mundo de la vida acontece un vacío de sentido que es llenado por máquinas, cualidades primarias, objetos materiales y representaciones digitales. Sin embargo, la fuente del valor humano reside en aspectos relacionales, procesos donde el ser humano se vincula con los otros, incluso, con el gran Otro. La tecnología por la tecnología es la consumación del nihilismo ¿Acaso una carencia ha impulsado esa nueva era geológica dominada por la tecnología, casi en exclusividad?

Frente al modelo de sujeto separado y distante, cada vez más investigaciones demuestran "que la naturaleza humana no se caracteriza por buscar la autonomía —convertirse uno mismo en una isla— sino por buscar la compañía, afecto e intimidad" (Rifkin, 2010: 29). Diversos psiquiatras y pediatras rompieron con el principio de realidad de Freud. Fairbairn (1978) mostró que el amor es la clave de la personalidad de la etapa infantil. Si el niño siente que su amor no es correspondido, y no hay reciprocidad, es fácil que muestre síntomas patológicos —ansiedad, aversión, agresividad o exceso de dependencia. Evitar los sentimientos de abandono y soledad es clave para el desarrollo emocional y social. El bebé, y después el niño, se dedica a establecer relaciones, vínculos con sus cuidadores primarios. Frente al interés primario egoísta de los enfoques freudianos, la necesidad de establecer vínculos y relaciones con sus cuidadores es su interés fundamental, el "principio de realidad". Ian Suttie (1935) desarrolló una teoría de la mente infantil que demuestra la necesidad innata del ser humano de compañía respondiente. Evitar la sensación de soledad existencial y, en su lugar, garantizar que el niño se sienta amado es una de las claves del desarrollo. Suttie (1935: 49) llega a afirmar que "buscamos el poder como camino para lograr el amor". El interés egoísta es un impulso secundario cuando se produce un "déficit de ternura"; el principio del placer es un mal sucedáneo cuando no hay un desarrollo emocional y social maduro. Flugel (1945: 246) citó a Suttie en *Man, Morals and Society* para argumentar que "la mayoría de las formas de agresión, delincuencia, angustia, junto con la sed de poder o admiración, son productos del amor frustrado". Descubrimos, entonces, que desde el principio del desarrollo humano existe la necesidad de forjar vínculos afectivos. Leyendo a Martin Buber (1968: 28):

> Desde el grado precoz y más restringido de la vida personal se puede observar la naturaleza prístina del esfuerzo para satisfacer la necesidad de relación. Antes aún de que pueda percibir cosas aisladas, tímidas miradas del niño buscan en el espacio indistinto algo indefinido; y en el momento en que, visiblemente, no desea alimento alguno, los delicados ademanes de sus manos, lanzados en el vacío, procuran, en apariencia sin objeto, encontrar algo.

El apego es un proceso que no termina con el parto o la lactancia "sirve de base a todas las relaciones afectivas en la vida y, en general, a todas las relaciones entre miembros de la misma especie. En los mamíferos existe apego en las diferentes especies" (Moneta, 2014: 266). John Bowlby (1986), con su teoría del desarrollo infantil, demostró la necesidad de equilibrar apego seguro y exploración para adquirir la madurez emocional que permite relacionarnos con el resto de las personas en el "orden del ser", evitando las relaciones superficiales, las del "ámbito del tener". En el orden del ser, el apego hacia personas significativas —con las cuales hemos formado un vínculo duradero—, nos acompañará toda la vida. El apego seguro reduce las actitudes objetivantes y tiene lugar el encuentro, la compañía, el afecto: los vínculos primarios que dejarán su impronta hasta la vejez.

Buber afirmó en *¿Qué es el hombre?* que "el individuo es un hecho de la existencia en la medida en que entra en relaciones vivas con otros individuos" (Buber, 1973: 146). Las relaciones se basan en la confianza. Y la confianza es la clave de la sociabilidad, recibir al otro sin barreras. La desconfianza produce la distancia que nos lleva a tratar a los demás como un objeto —algo a manipular—, lo que da lugar a relaciones superficiales y utilitarias. La sensación de sentirse querido es clave para el desarrollo de la sociabilidad. De lo contrario, corremos el riesgo de vivir una sociedad donde los seres humanos únicamente coexisten y se relacionan para satisfacer sus propios fines individuales, es decir, como si las relaciones humanas solo tuvieran sentido si tienen valor instrumental. Lo que no tiene utilidad no tiene valor: el ser se reduce a la utilidad. Gabriel Marcel (2003) en *Ser y Tener*, hace referencia a un mundo utilitario de problemas susceptibles de solución, el modo de la técnica. En el ámbito del tener, se dan las situaciones objetivas, aquellas en las que acontece la distancia necesaria para que el sujeto se enfrente al mundo de forma desinteresada, no partícipe, tratándolo como un objeto exterior. Es el comportamiento despegado y distante en el que late la separación moderna entre cualidades primarias, objetivas, y cualidades secundarias, subjetivas. Las cualidades secundarias se representan en el escenario del cuerpo, y dan lugar a sentimientos y emociones. La realidad nos impacta a través de todos los sentidos, nos toca, nos afecta. En el ámbito del ser, el otro nos afecta con todos los sentidos, participando emocionalmente en nosotros mismos. El ámbito del ser nos debe llevar de la coexistencia a la convivencia, en la que se forjan los vínculos reales. En la distancia la relación es virtual, en la cercanía la relación es participativa, real. El otro no se agota —como los problemas, que tienen solución—, siempre queda una apertura y un misterio trascendente:

> Parece, en efecto, que entre un problema y un misterio hay una diferencia esencial, la de que un problema es algo con lo que me enfrento, algo que encuentro por entero ante mí, que por lo mismo puedo cercar y reducir, en tanto que un misterio es algo en lo que yo mismo estoy comprometido y que, en consecuencia, no es pensable sino como una esfera en la que la distinción del en mí y delante mí pierde su significado y su valor inicial. Mientras un problema auténtico puede ser sometido a cierta técnica apropiada en función de la cual se define, un misterio transciende por definición toda técnica concebible. (Marcel, 2003: 109)

En un espíritu similar Emmanuel Lévinas alertó de la pretensión de un desvelamiento completo, de apresar totalmente al Otro en lo Mismo, cayendo en la trampa de un dominio absoluto, sin misterio. Lévinas supone una alternativa ética a la indagación de Heidegger sobre el sentido del ser, "sitúa la cuestión del sentido en el marco primigenio de la alteridad y el origen de la subjetividad humana, una subjetividad entendida como responsabilidad inderogable, responsabilidad convocada acaso por la voz de lo Infinito" (Barraca, 2008: 61). Para Lévinas, hay que entender que el otro no entrega por completo su verdad porque está presente en él una idea de infinito que lo impide, más allá de las apariencias objectuales: "su alteridad se manifiesta en un señorío que no conquista, sino que enseña. La enseñanza no es una especie de género llamado dominación, una hegemonía que funciona en el seno de una totalidad, sino la presencia de lo Infinito que hace saltar el círculo cerrado de la totalidad" (Lévinas, 2002: 189).

El Otro como misterio nos abre al pensamiento del ser, de lo infinito, el Otro como algo irreductible e inapresable. El acontecimiento de la trascendencia en la inmanencia da lugar a prácticas distintas a las que acontecen con el lenguaje óntico-tecnológico. Nos abre a la actitud receptiva, de escucha, silencio y atención. Una iluminación que no es la del dato ni la de un conocimiento que podamos comprender de una vez por todas. La apertura hacia un sentido más allá de lo que se presenta, se posee y se domina.

Conclusión

La pandemia ha acelerado la transformación digital. La digitalización ha permitido adaptarnos con mayor facilidad a esta nueva y difícil realidad. Sin embargo, la tecnología y la digitalización —y el espacio virtual en el que nos introduce—, se sitúan en un plano alejado de la comprensión plurisensorial y afectiva de nuestro mundo. La necesidad de distancia para evitar los posibles contagios puede hacernos olvidar aspectos corporales, emocionales y sensibles. Por eso es necesario reflexionar sobre los valores transversales que deben ocupar este nuevo contexto.

Con la presencia de lo infinito se evoca una diferencia imposible de reducir a cálculo y medida. Es un enfoque distinto a la búsqueda del dominio que la reducción del mundo a magnitud permite. El mundo digital no es capaz de registrar las diferencias de la realidad, pierde partes de mundo al traducir la información al lenguaje de los números. Realidad, información, dígitos; en el mundo digital perdemos parte del mundo y vivimos en un mundo virtual que reduce los matices de la realidad. En el mundo real, un enfoque plurisensorial permite reconocer todas las diferencias que el pensamiento de la representación abstrae y reduce. Lógica, computación y digitalización; hacen que el mundo del tener sea cada vez más potente y exitoso, pero nos alejan del mundo del ser, de los vínculos y las relaciones esenciales. El mundo del ser nos hace sentirnos dentro del mundo real.

La búsqueda primaria de compañía, la importancia del afecto en el desarrollo de la personalidad o evitar reducir el misterio del otro —sometiéndolo a nuestra voluntad y control—, son valores que pueden o deben guiar la era tecnológica. Como consecuencia se espera que las relaciones dejen de ser virtuales o utilitarias, sustituyéndose por vínculos vivos, sensibles y perceptibles. Se trata de lazos reales, encarnados en cuerpos y mentes capaces de superar la distancia en un encuentro plurisensorial, afectivo y abierto.

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PROJECT MANAGEMENT IN THE FOURTH INDUSTRIAL REVOLUTION

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KEY WORDS

Fourth Industrial Revolution
Project Management
Green Project Management
Sustainability

ABSTRACT

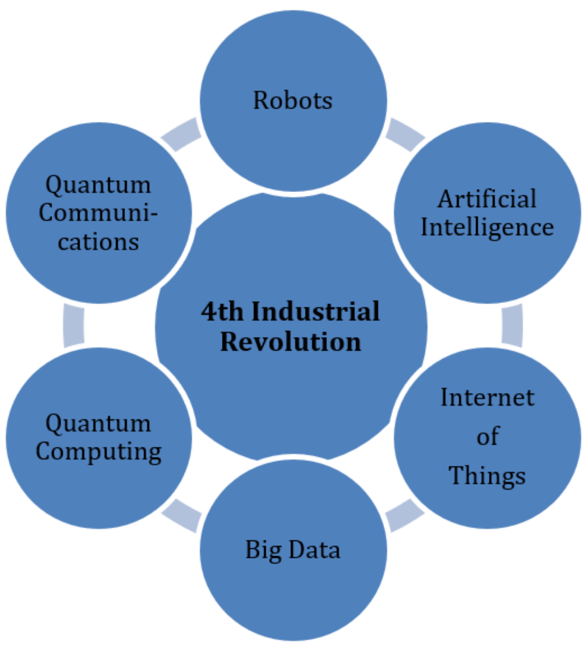
The Fourth Industrial Revolution (also referred to as Industry 4.0) is driven by a massive utilization of new technologies, such as robots, artificial intelligence, Internet of Things (IoT), Big Data, Quantum Computing and Quantum Communications, replacing humans by machines in certain tasks or the development of new or more efficient tasks. The Fourth Industrial Revolution is originating huge modifications in society and organizations. Human adaptation to the new paradigm is required, as it will have a high impact on jobs and on the required skills. Project Management has evolved significatively in the last decades, privileging the fulfilment of the scope, time and cost of projects, based on the "triple constraint" classic model, and is still evolving due to the needs of new projects in the Fourth Industrial Revolution. This evolution has taken us to more complex models, with greater concern for the benefits that a project will bring to society and environment, which is a great challenge for Project Managers.

GLOBAL KNOWLEDGE ACADEMICS

1. Introduction

Using robots and artificial intelligence, the Fourth Industrial Revolution is already deeply modifying society and organizations (Kunze et al., 2018). As can be seen in Figure 1, the Fourth Industrial Revolution comprises other parameters than only robots and artificial intelligence (Griffiths and Ooi, 2018). Robots need to communicate and to sense the environment (using sensors and communications), for which Internet of Things[1] is utilized. IoT generates massive quantities of data (big data) that will be processed with artificial intelligence to generate knowledge, i.e., to support the decision making or to make decisions using robots (Mariani, 2017).

Figure 1. The Context of the Fourth Industrial Revolution



Source: Adapted from Author, 2020

These new technologies will originate a deep change in society, with high impact on the way we live, on organizations, as well as on the employment market.

The first profound change in the way we live took place 10,000 years ago, when, thanks to the domestication of animals, humans stopped searching for food and started agriculture. The agricultural revolution was followed by several other industrial revolutions that started in the second half of the 18th century, which can be defined as:

- First Industrial Revolution (1760 to 1840): use of the steam engine in industry and in the railways;
- Second Industrial Revolution (1850-1945): use of electricity and introduction of assembly lines;
- Third Industrial Revolution (1950 to 2000): digital revolution and media era, as well as information systems and technologies.

Like the Third Industrial Revolution, the Fourth Industrial Revolution will make some jobs disappear and others appear. Also, as before, new and higher levels of skills will be demanded to face the new environment. Instead of having the previously described transforming view of employability, some people have a very pessimistic view, forecasting that most jobs will be replaced by robots, leaving most people unemployed (Rainai and Kocsis, 2017). Nevertheless, similar pessimistic view of the Third Industrial Revolution was foreseen by some people, but the reality proved that employment simply changed. rather than suffer a chaotic impact. While replacing repetitive human activities and reducing the risk of accidents (e.g., professional or car accidents with autonomous cars), robots will bring added value to elderly people and those with disabilities (Marques da Silva, 2019). Nevertheless, like other technologies, negative outcomes and impacts will depend on peoples' values and way of use.

Project Management has existed since man began building in an organized manner, and there is evidence that in older civilizations there were already defined and followed rules in the construction of buildings and roads. In ancient civilizations (Greek, Egyptian, Roman, Asian and pre-Columbian American civilizations), the need to build accurately, according to established plans, respecting defined costs and deadlines, clearly indicates a concern with Project Management (Cabeças, 2018).

Frederick Taylor (1856-1915) was one of the pioneers of management techniques applied to

[1] All data is transmitted over the IP Protocol, while machines communicate, instead of people.

industry, having published. in 1911. the book "Principles of Scientific Management", considered a reference in this area. Henry Gantt (1861-1919), a disciple of Frederick Taylor, is considered one of the most important drivers of planning techniques and project control, having become known for his use of bar charts as a support tool for Project Management, now called "Gantt Charts". He was the first to use milestones for deliverables, task duration, and estimates. Although improved with more recent techniques, such as dependency definitions, the essence of content and format, Gantt Charts have remained virtually unchanged for 100 years. But it is consensual to consider that, in the 1950s, when the modern era of Project Management began, with the development of the PERT and CPM models, currently known as PERT/CPM [2] (Cabeças, 2018).

In 1967, the International Project Management Association (IPMA) was founded in Europe, bringing together project management associations from various European countries. In 1969, the Project Management Institute (PMI) was created in the United States of America, with the aim of finding ways to improve Project Management. PMI started the development of the Project Management Book of Knowledge (PMBoK), which defines the standards and practical guidelines for Project Management, which quickly became one of the main guides in this area, followed worldwide (Cabeças, 2018).

Thus, according PMBoK, Project is a temporary effort carried out with the objective of creating a specific product or service; Project Management was defined as the application of knowledge, skills and techniques to design activities aiming to achieve or exceed the needs and expectations of the parties involved with regard to the project. Project Management presupposes the existence of Project Managers, who must have the appropriate professional qualifications and profile to be able to manage a project (PMI, 2013).

The European Commission developed PM² in 2007 for application to EU projects and, in 2012, the ISO 21500 Standard was issued, with a generic guideline and description of the fundamental principles for good practices in Project Management.

This paper is organized as follows: section 2 describes the Impacts of Industry 4.0, while section 3 describes Evolution of Project Management in the Scope of the Fourth Industrial Revolution. Finally, section 4 concludes this paper.

2. Impacts of Industry 4.0

Schwab, K. (2016), the President of the World Economic Forum, stated the following about the Fourth Industrial Revolution: "The changes are so profound that, from the perspective of human history, there has never been a time of greater promise or potential peril".

The way we interact is undergoing profound and rapid changes, with an impact on the family environment, friendship and on the different relationships, as a result of multi-contact (Marques da Silva, 2019). However, there tends to be a progressive loss of freedom, with greater social exposure, and there is the risk that some people become slaves of technologies, rather than use them to make their lives easier. Depending on how people, organizations and countries manage technologies made available by the Fourth Industrial Revolution, several impacts can occur (Marques da Silva, et. al., 2018):

- Improvement of employability, with fewer hours of work per week and enhancing teleworking;
- Improvement of Communication and mobility, reducing distances and contributing to Globalization;
- Democratization of resources, information and knowledge, and an education more personalized to individual needs;
- Increased life expectancy and quality of life and well-being;
- Better autonomy and quality for people with disabilities and chronic diseases, as well as elderly people;
- Greater participation of individuals in social activities.

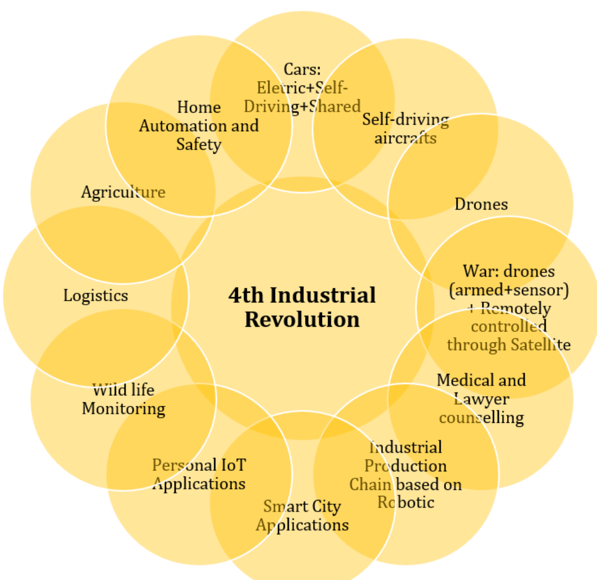
Robotization tends to facilitate everyone's domestic and routine activities, using devices such as smart vacuum machines or kitchen robots. The availability of new technologies will

[2] Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM)

enhance the creation of new devices that will continue to act as facilitators for the average person, as well as for the most vulnerable, such as the disabled or the elderly. One of the limitations of the elderly with mobility difficulties is the difficulty of acquiring food. A smart refrigerator, with Internet of Things, which makes automatic purchases over the Internet when the food stock drops below a certain threshold, will be a great facilitator. This functionality will tend to be extended to the smart kitchen, rather than the simple smart fridge (Marques da Silva, 2019).

Industry 4.0 is deeply modifying society and organizations in several areas, as detailed in Figure 2. This includes a more efficient mobility based on self-driving cars, smart cities, intelligent industries, medical and lawyer counselling, the use of intelligent drones for a myriad of areas, including in defence, etc. (Zhou et al., 2015).

Figure 2. Potential areas modified by the Fourth Industrial Revolution



Source: Adapted from Author, 2020

According to Schwab, K. (2016), the Fourth Industrial Revolution is different from previous revolutions in terms of:

- Velocity: It evolves at an exponential and non-linear pace. This is the result of the multifaceted and deeply interconnected world in which we live. In addition, new technologies generate newer and more qualified ones;
- Amplitude and depth: It is based on the digital revolution and combines several technologies, leading to unprecedented paradigm shifts in economy, business, society and individuals;
- Systemic impact: It involves the transformation of entire systems between and within countries, into companies, industries and across society.

We are experiencing a new reality with a systematic and profound change, which recent examples from companies such as Airbnb, Uber, Alibaba, Google (autonomous car) or WhatsApp, help to illustrate. Goodwin (2015) said that "Uber, the largest taxi company in the world, does not even have a vehicle. Facebook, the world's popular media owner, does not create any content. Alibaba, the most valuable sales site, has no stocks. Airbnb, the largest hosting provider in the world, doesn't even own a property.".

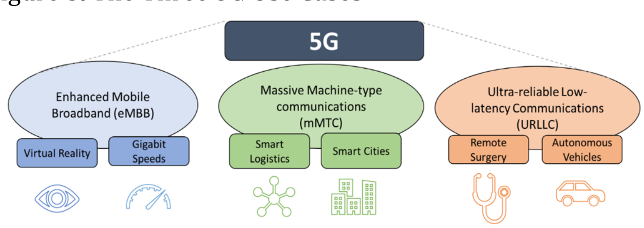
Besides the change of paradigm in the way businesses are implemented, the Fourth Industrial Revolution contributes to a more efficient use of resources. Uber helps optimizing the use of cars, while Airbnb helps optimizing the use of properties.

Massive use of self-driving cars boosts their sharing, which translates into more efficient mobility and more efficient use of resources. Therefore, instead of using a car for a short percentage of time, while the car is getting older, the sharing of cars is expected to be the future of mobility (Febbraco et al., 2019). Therefore, either one purchases a car and shares it with others, while not in use, or one simply uses a car that is shared by someone else. This view is reinforced because, with self-driving cars, driving license is not required, and the risk of accident is much reduced, as compared to current cars.

5G communications play an important role in autonomous driving using the mode Ultra-reliable Low-latency Communications (URLLC). As can be observed in Figure , URLLC was designed to support new services, such as remote surgeries or autonomous vehicles, services that are delay sensitive and that require a very low bit error rate (errors are almost unacceptable). Therefore, URLLC is about high-speed, low-latency vehicle-to-vehicle communications (V2V), in addition to conventional communications through a base station. 5G, using millimetre waves, i.e., frequencies of around 60 GHz (RAPPAPORT, T.S. et. al. (2013)), will allow rapid sharing of large amounts of information in V2V communications, such as position, course, speed, position of origin and destination of the trip, surrounding traffic, etc. (Marques da Silva, 2019).

MIMO system (multiple transmit and receive antennas) consists of a technology that, alongside with millimetre waves, supports the demanding requirements of 5G communications. This allows an exponential increase in transmission rates through the exploitation of multiple parallel flows of data (tens, hundreds or even thousands of times higher) between each transmit and each receive antenna (Marques da Silva, M., and Monteiro, F. (2014)) (Marques da Silva, and Dinis, M. (2017)). In addition to autonomous driving, 5G, through Internet of Things, will boost the implementation of smart cities, remote surgeries, virtual reality, smart logistics, etc. As can be seen in Figure 3, Massive Machine-type communications (mMTC) is the mode that supports Smart Cities, by implementing Internet of Things using massive quantity of devices that send low amounts of data, and using low power levels. Finally, Enhanced Mobile Broadband (eMBB) mode aims to provide wide coverage using a base station. Note that 5G will be implemented in different phases: the first phase comprises eMBB, as defined by 3GPP release 15, while URLLC and mMTC are defined in 3GPP release 16, to be implemented in a later stage.

Figure 3. The Three 5G Use Cases



Source: Adapted from Author, 2020.

While human, social and organizational efficiency tends to improve with the fourth industrial revolution, human freedom needs to be maintained, and special attention should be paid to the new ethical issues that arise. Regulation plays a fundamental role, as well as the correct individual and organizational use of technologies, so that they act as facilitators to human lives and organizations, instead of making them slaves to these technologies (Marques da Silva, 2019).

2.1. The Employment Market in the Context of Industry 4.0

Some more pessimistic analyses present a view that the substitution of humans by robots will result in a high level of unemployment. Similar fear occurred with the third industrial revolution, which was not experienced. Others believe that the Fourth Industrial Revolution will lead to the disappearance of some jobs, but to the appearance of others, while a higher level of skills is required (Marques da Silva, 2019). A recent study undertaken by the Organization for Economic Co-operation and Development (OECD) indicates the following influences of the Fourth Industrial Revolution on employability (OECD, 2018):

- Automation mostly affects industry and agriculture, but the services sector is also vulnerable to automation;
- The greatest risk is found in the most routine jobs, with low qualifications and underpaid;
- About 14% of existing jobs in OECD countries are highly automated, while 32% of jobs can undergo a substantial change in the way they are performed;
- The lowest risk is applicable to a wide range of jobs related to the creation, maintenance and administration of technologies, creative intelligence, organizational manipulation, as well as social intelligence, such as social understanding and personalized care for dependent people;
- Young people entering the job market are more vulnerable to automation

than jobs held by more experienced people;
- Not all technically automated jobs will disappear. In addition, other jobs will be created, with the expectation that employability will continue to increase.

Bill Gates and Elon Musk have warned us about the job market issue, which has been discussed at the World Economic Forum, and that about five million jobs will be lost by 2020 in the main world economies, as a direct consequence of industry digitalization. Elon Musk thinks we must be very careful with the evolution of Artificial Intelligence (AI) or we will end up in a world dominated by "Google created killer robots". But Bill Gates does not agree with this view, considering that we have nothing to fear in the future. Mark Zuckerberg, creator of Facebook, and John Giannandrea ex-Google, now at Apple, agrees with Bill Gates, stating that humanity only has to benefit from the use and evolution of Artificial Intelligence.

Schwab, K. (2016), states that experts warn about the gap between rich and poor widening, as only those who are technologically well prepared will take advantage of this new revolution. Thus, solutions and new answers will be needed so that the risk of increased unemployment can be mitigated. There may even be new opportunities to mitigate this risk, as, according to a recent study by the International Labour Organization (ILO), between 120 and 150 new professional activities will emerge in the next 50 years, many of them generated by the technology itself.

2.2. The Problem of Global Security

Schwab, K. (2016) warns his readers that a hyper-connected world, with increasing inequalities, may lead to an increase in fragmentation, segregation and social unrest that, in turn, will allow for violent radicalism. This author also considers that cyber wars may arise, in which an adversary can disturb, confuse or destroy the sensors, communications and decision-making capacity of enemies, in which the traditional physical borders of countries will be irrelevant. Information Security relies on a set of controls, such as policies, legislation, processes, procedures, organizational structures, software, and hardware functions.

We live in an era when human beings are electronically controlled in different ways. They are controlled by banks through the movement of their credit cards, by telecommunication operators through the human use of the cell phone, by Internet Service providers, by social networks, by operating systems such as Android (Google) and iOS (Apple), by surveillance cameras installed in cities and streets, etc. Therefore, while the efficiency and level of security tends to be improved with new technologies, the freedom and confidentiality of data is in danger. There are already cities where surveillance cameras are associated to artificial intelligence. This allows a security system of a city to track each human, as well as his or her behaviour. Nevertheless, depending on the way information is managed and secured, human freedom and confidentiality can be at risk.

The new General Data Protection Regulation (GDPR), laid down in the European Union Regulation 2016/679, was published on 4 May 2016, and entered into force in 2018. This regulation aims to:

- Harmonize data privacy laws across the European Union (EU);
- Protect and enable all EU citizenship data privacy;
- Redefine how organizations across the region address data privacy.

Human behaviour, as well as organizational behaviour, in view of technologies is the key issue to define whether or not the latter bring added value to each person or organization. Are relationships more efficient and more human, do people feel closer to one another, are they happier? In the past, a process that was managed via two or three letters is now managed using several dozens of e-mails, with much unstructured information. Handwriting and mental multiplication tables are getting lost and dyslexia is increasing as a result of the widespread use of technology. Therefore, technology can make people slave to machines but, on the other hand, it may improve human, social and organizational efficiency, and fight poverty, disease and ignorance. It depends on the way we use technology. 10 USD smart Phones are reaching the poorest countries in the world, eliminating asymmetries, massifying the use of technologies, information and knowledge, and therefore, reducing inequalities. It is worth noting that, as result of higher level of dependency on technologies, Industry 4.0 tends to make companies more capital intensive. This is increasing the asymmetries between small and big companies.

In addition to changes in growth patterns, labour markets and the future of work, there is evidence that Industry 4.0 technologies represent a major impact on how companies are led, organized and managed, with the following impacts:

- Customers' expectations are changing;
- Products are being improved by data, which improves asset productivity;
- New partnerships are being formed, as companies learn the importance of new forms of collaboration;
- Operational models are being transformed into new digital models.

Using artificial intelligence, medical and legal counselling tends to be more efficient and more effective when provided by computers, instead of humans, reducing the risk of errors. Surgery tends to be more effective, and with lower level of risks, when performed with the support of robots. On the other hand, wars tend to be more technology dependent, using drones, armed with sensors, controlled through satellite, and remotely operated from other parts of the globe. In the case of a tactical war, a micro-drone can play an important role by increasing surveillance, while minimizing the risk to the troops involved.

One can imagine a micro-drone, equipped with a camera, with artificial intelligence, and armed. What could be the impact of using thousands of these micro-drones in a city, to perform a specific and autonomous attack? What if a terrorist organization could create and use such micro-drones? While the conventional war is protected by international agreements and national legislation, new technologies originate a change in paradigm. Nowadays, the nuclear weapons non-proliferation treaty controls the development of nuclear weapons. Nevertheless, new technologies, such as micro-drones, armed, and equipped with artificial intelligence, can be similarly dangerous, but much easier to be implemented, and therefore easily out of control.

Current Microsoft President Brad Smith said at the 2017 Web Summit that cybersecurity must be one of the great causes of our time. Cybersecurity is the term used for the means and technologies used to protect networks, computers, programs, files and data, in response to cybercrime. Information security and data security must be guaranteed, as these are very important assets for any organization, knowing that information security also involves, processes and people, not only technology, and it is required to implement an appropriate set of controls, including policies, processes, procedures, organisational structures, software and hardware functions.

The new risks that arise from the use of new technologies by terrorist organizations originate a shift in paradigm, and global control, instead of control limited to the borders of a country. This is only possible with a collaborative attitude among different countries, instead of the simple and usual competitive attitude.

3. Evolution of Project Management in the Scope of Industry 4.0

As mentioned before, Project Management has existed since humans began to build in an organized manner, but only in the late 19th and early 20th century, Frederick Winslow Taylor (1856-1915) applied scientific reasoning to the work, demonstrating that manpower can be analysed and perfected. He applied his reasoning to routine tasks performed in factories and, to improve productivity, he introduced the concept of working more efficiently instead of working longer hours, focusing on the organization of production processes and training. Henry Gantt (1861-1919) was one of the most important drivers of project planning and control techniques, having become known for the creation of the famous "Gantt Charts”. It is consensual to consider that it is in the 1950s that the modern era of Project Management begins, models PERT and CPM were developed at that time, later called PERT/CPM by its joint use. In 1967, the International Project Management

Association (IPMA) was founded in Europe and, in 1969, the Project Management Institute (PMI) was established in the United States of America, with the aim of finding ways to improve Project Management. In 1981, PMI started the development of the PMBoK, which defines the standards and practical guidelines for Project Management, which quickly became one of the main guides in this area, followed worldwide. The European Commission developed PM2 in 2007 for application to projects within the European Union and in 2012 the ISO 21500 Standard was issued, with a generic orientation and description of the fundamental principles on best practices in Project Management.

3.1. Recent developments in Project Management

The classic model of Project Management, known as Triple Constraint, considered that if a project was completed in the planned time, with the expected cost and the agreed scope, it would be a quality project and, if it met the expectations of its Stakeholders, it would succeed. This model may be represented by figure 4.

Figure 4. Triple Constraint

Source: Adapted from Author, 2018

In this model it is considered that a project has quality if time, cost and scope are achieved. Kerzner (2006), an American engineer known for his work in the areas of Project Management, states that at the beginning of the application of the techniques and concepts of Project Management, concerns were strongly oriented towards cost and time risks. From the 80's on, companies began to feel the need to work with risks through their impact on scope, cost, time and quality objectives.

The PMI report "Pulse of the Profession 2018 - Success in Disruptive Times" refers, based on rigorous statistical studies, three "top drivers" for the success of a project:

1. Investing in the active involvement of executive Sponsors;
2. Avoid increasing the scope or unchecked changes in the project scope;
3. Mature capabilities for value delivery.

Recent PMI statistics confirm that more than 50% of projects that fail are due to communication problems, poor planning and setting unrealistic deadlines.

Kerzner (2014) asked during an interview the following question: "You only get value from a project when it adds something positive and meaningful to the business, but how many projects add value?". If a project does not add anything to the business and society, it can be considered a useless project, since, currently, the goals of a business are also being seen from other perspectives besides the traditional profit, such as ethical and sustainability perspectives that are now being considered even more important.

The development of sustainable projects has become increasingly important for organizations. ISO 26000 defines sustainability as "integrating the goals of a high quality of life, health and prosperity with social justice and maintaining the earth's capacity to support life in all diversity", so organizations have to develop new projects in a sustainable perspective with respect to stakeholders' expectations on social responsibility (IPMA, 2016).

It is also important that Project Management is aligned with the organizations' strategy, and strategies should be understood and transformed into elements that can be managed through projects. In this sense, a management system is being defined, in which projects are seen and managed in light of their alignment with organizations' strategy and vision, ensuring their high correlation with the organization's mission and sustainability (IPMA, 2015).

Green Project Management (GPM) is defined as a model in which we think about our project with an environmental concern, making decisions that consider their impact on the environment. It is a way of thinking green in each of the five Project Management Process Groups[3], from a sustainability perspective, defined as supporting some condition, something or someone in some process or task, with good use of natural resources, with strong concern for the environment and welfare. GPM Global, based in the USA, considers the evolution of this traditional model to a more complete one, in which new components are added, besides the traditional ones of Triple Constraint, according to the perspective represented in figure 5.

Figure 5. GPM Global Model

Source: GPM, 2019.

In this model, GPM Global (2019) considers that Project Managers should focus on time, cost, quality, scope, benefits and risks, and should also consider the five "P's", which are referred to in the document "The GPM P5TM Standard for Sustainability in Project Management", People, Planet, Prosperity, Processes and Products, highlighting their importance to achieve good Project Management and the creation of sustainable projects.

All these issues arise as a consequence of ongoing movements in a global society, increasingly based on a process of globalisation, and it is important to ensure that projects are truly sustainable, in which they not only contribute to meeting the needs of their stakeholders, but also add value to the environment and to society as a whole.

3.2. Project Management Technology Quotient

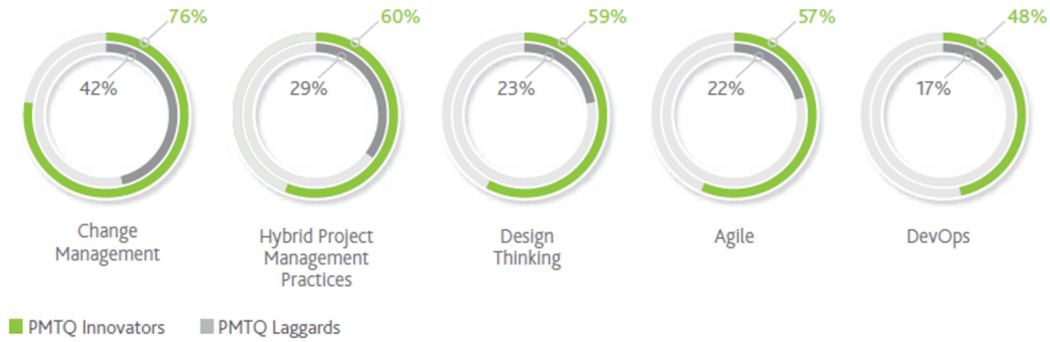
PMI Pulse of the Profession (PMI, 2019) mentions that, in a 2019 PwC survey, in which a significant sample of CEOs participated, 85% of the respondents believe that artificial intelligence will significantly change the way they do business in the next 5 years, as well as mentions the importance of the Project Management Technology Quotient (PMTQ). QT is Technology Quotient, referring to a person's ability to adapt, manage and integrate technologies based on the needs of the organization or project in question. People and companies seek digital sustainability as the ability to adapt to the constant whirlwind of change caused by advances in technology. Associated with the changing nature of work from "lifetime employment" to "project portfolio", we see a greater demand for QT combined with Project Management, and the QTPG is emerging. For those responsible for making business strategy a reality in a world constantly changed by technology, the QTPG will be a set of compulsory skills to define success or failure (PMI, 2019).

According to PMI (2019), regarding the approaches used by PMTQ Innovators Versus the PMTQ Laggards, represented in figure 6, we may verify the importance of using PMTQ in a variety of project management approaches, such as Change Management, Hybrid Project Management practices, Design Thinking, Agile and DevOps.[4]

[3] According to the PMBoK, the five Project Management Process Groups are Initiating, Planning, Executing, Monitoring and Controlling, and Closing.

[4] DevOps is the combination of development and operations, being a software engineering practice that aims to unify software development (Dev) and software operation (Ops).

Figure 6. Approaches Used: PMTQ Innovators Vs the PMTQ Laggards



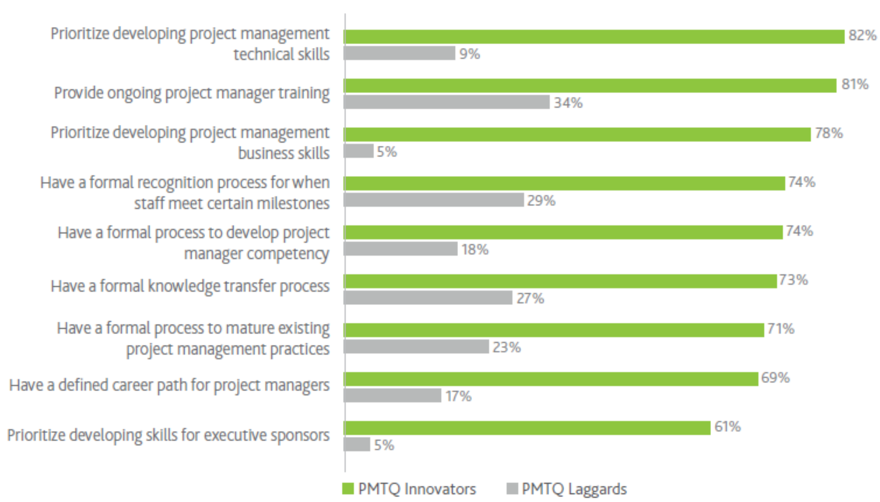
Source: PMI, 2019.

In figure 7 we can see some of the process and project management capabilities that show what PMTQ Innovators rely on, which is a quite different path from the PMTQ Laggards, emphasizing, as examples, priority development of project management technical skills, providing ongoing project manager training and prioritize development of project management business skills.

With the information in figure 8 we may also confirm that the PMTQ innovators have better projects performance metrics, enhancing as significative examples, meeting f the original project goals, the projects budget and the time planned for the projects.

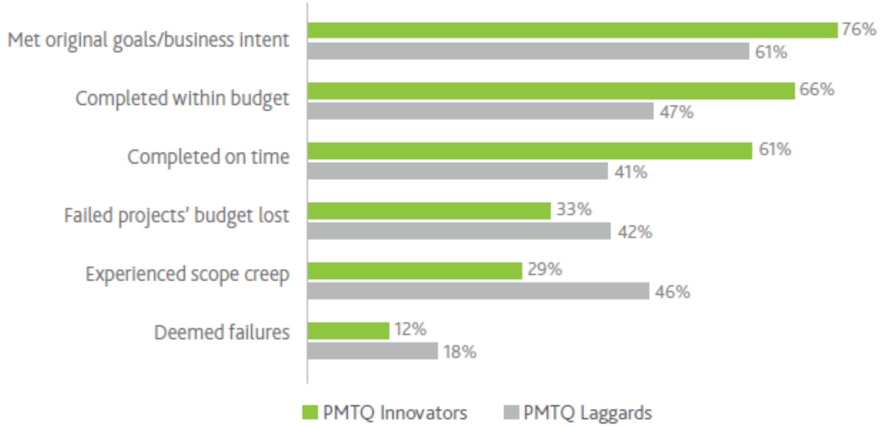
Organizations that are PMTQ Innovators are better prepared to take the lead on project outcomes. This not only means PMTQ Innovators save money and improve stakeholder's satisfaction rates, but also that the percentage of project investment wasted due to poor project performance is less than the PMTQ Laggards (8.5% versus 16.3%). Their projects are more likely to meet their original goals and be delivered on time and within budget while reducing scope creep and outright failure, leading to success (PMI, 2019).

Figure 7. Processes and Capabilities: PMTQ Innovation Vs the PMTQ Laggards



Source: PMI, 2019

Figure 8. Project Performance Metrics: PMTQ Innovation Vs the PMTQ Laggards



Source: PMI, 2019

3.3. The evolution of Project Management

The demands of connected and digital organizations operating in disrupted and rapidly changing landscapes, dominated by challenges of integration speed, are applying new levels of challenge to project and program management across the world (KPMG, 2019).

The methods and tools used in Project Management tend to evolve in view of the needs of projects associated with new technologies and with the use of Artificial Intelligence. It is unanimous that the tools used to support Project Management will evolve and will be more intelligent and sophisticated, and in addition to the planning and control components of the projects include functionalities to improve information sharing. The tools to support Project Management have evolved and there is an increasing supply in this area, and the evolution of Project Management models, whether traditional Waterfall or Agile project approaches[5] are also following the technological evolution. Larger volumes of data (big data) will be available for analysis and sharing and many of the routine tasks Project Managers perform today will be automated.

KPMG (2019), based on a collaborative research survey undertaken in Australia in 2018, extended in 2019, with the assistance of IPMA and AIPM, to the global membership base of IPMA and associated regional partners, along with select KPMG client representatives, refers the following several key topics that are emerging or continuing to grow related with Project Management:

- Project management is being increasingly used to drive organizational strategy and success and has moved beyond merely delivering outcomes for business to pick up and adopt;
- The overall sense of success rates of projects continues to be low when viewed through the lens of cost, time, scope and stakeholder satisfaction;
- The importance of sponsorship in the project eco-system continues to be a key factor in project success;
- Collaboration software usage is increasingly being recognized as important in assisting in complex and large projects and has a link to success;
- Opinions remain divided about the effectiveness of enterprise wide PMOs;
- The use of Agile approaches is becoming more widespread;
- Change management is an increasingly important skill and knowledge area for PMs; and
- Project management as a skill continues to grow in importance.

The skills and areas of project management are being used to face business challenges. In time project delivery is essential for the modern organizations as a tool for delivering strategic change and driving bottom line performance

[5] Scrum, Kanban and Lean are some samples of Agile approaches.

improvement. Increasing focus on closing the gap between business needs and project delivery, through the application of Agile approaches, appear to be on the increase to further address these deficiencies. Also, there is evidence that engaged senior stakeholders have a significant positive impact on the likelihood of project success. Increasingly, Agile and adaptive approaches to deliver strategic outcomes through projects and programs require quicker and more insightful leadership from the Project Management Offices (PMO). It is also important to mention that automation, data analytics and artificial intelligence are increasingly offering new and improved ways of monitoring performance, identifying deviations from plan and underlying risks and issues (KPMG, 2019).

According to KPMG (2019) inquiry data it was possible to verify that the use of recognized project management software, tools and techniques is widespread, showing that 71% of organizations reported using project management software to improve the management and control of programs and projects. Specifically, 39% are using specialist PM software, 20% are using an in-house solution, while the remaining 12% are using non-PM commercial software. MS Project/Project Online is the tool used most readily. The level of maturity in development and use of software is generally identified as being 'operational' by close to half of all organizations. Usage of collaboration software is significant, with 51% of organizations using collaboration tools to support project delivery. At this stage, only 8% of organizations globally reported using Artificial Intelligence tools to support their projects. Based on this survey data, KPMG (2019) also identifies, that Agile delivery approaches are in use in over 47% of the inquired organizations, which represents a significant increase, highlighting its importance.

It is a fact that the tools to support the activities of Project Management have also evolved a lot in recent years, and there is an increasing supply in this area. MS Project continues to be the most used tool in Project Management, but in recent years other tools have appeared, like the best-known Jira and Trello. There are also other tools[6], that have appeared in the last few years, some of which with strongly information-sharing oriented and new tools will certainly continue to appear and all will be subject to "Digital Darwinism", seen as a natural selection process by their clients (organizations and Project Managers), but only the best will prevail. Artificial Intelligence, defined by Ford (2015) as the replacement of human decision making, imitating the human thought-process and allowing the machine to learn as a human being, will contribute to the improvement of these tools. More data will also be available for analysis and sharing, and many of the routine tasks that Project Managers perform today will be automated.

According to GPM Global (2019), to achieve true digital sustainability in the new future of work, organizations will need teams "ready for everything" who know their technology and master the techniques and methodologies used to help the Project Management activity. Project Management will continue to evolve towards GPM Global, and Project Managers will have to adapt to a new reality that is emerging with the Fourth Industrial Revolution. Moreover, Innovative QTGP companies, which give priority to digital skills and knowledge, will be more successful in their projects (PMI, 2019).

In a recent Gartner publication, Henderson et al. (2019) reported that continuous delivery is driving more management leaders to connect strategic business investments aligned with diversified delivery, shifting delivery focus from time to value and PPM vendors that offer technology to support these ventures are better evaluated. According to these authors, the strategic planning assumptions are:

- By 2023, 80% of organizations will have an enterprise project, program or product management office (PMO) focused on integrating digital products and programs;
- By 2021, at least 40% of large enterprise IT organizations will have completed their implementation of a product-centric approach;

[6] Other examples of existing tools are AirTable, Artia, Asana, Basecamp, Bitrix24, Clickup, GanttProject, Hibox, Hive, Liquidplanner, Monday, Notion, Operand, Pipefy, Podio, Runrun.it, Slack, Teamwork, Wrike, etc.

- By 2023, 65% of organizations that moved to product-centric delivery will have embedded their digital product managers in a business area;
- By 2023, technology providers focused on artificial intelligence (AI), virtual reality (VR) and digital platforms will disrupt, and elicit a marked response from, the traditional providers within the project and portfolio management (PPM) market.

Wagner (2017), in a post published at IPMA website, mentioned that, for project management, the Fourth Industrial Revolution means an increasing number of new projects, an increasing importance of the management of such projects, with a different type of management, viewed as some kind of an "orchestration" or "facilitation". Projects are performed to enable the creation of innovative products and services, and they require a flexible and context-adaptive facilitation. People join for one project, dissolve and reassemble in a different composition. Teams are increasingly fluid and thus require a flexible style of organisation, like a nomadic tribe with tents or other hybrid organisations. The specialization of people working in projects requires them to acquire new skills in order to be attractive to the organisation and the leadership style will change as there are no dependent employees anymore but "co-workers".

3.4. Evolution of Project Managers' Behaviour

The truly successful Project Manager of the future will be more strategic than tactical, with an increased focus on working with business leaders to rapidly and incrementally deploy benefits to support the overall business strategy (KPMG, 2019).

Because of the Fourth Industrial Revolution and the evolution of Project Management itself, Project Managers will also have to adapt to the new reality. Bolick (2019), Professor at Northeastern University in Boston in the field of Project Management, summarizes that Project Managers can embrace digital transformation with four different approaches:

1. Promote the agility of change

The digital transformation is much more than the increase in computing power. Technological capabilities, internal resources and customer experiences are changing. The Project Manager must adapt to this new reality and will play a greater role in identifying value, facilitating creativity and increasing flexibility, serving as an agent of change and influencing multidisciplinary teams in organizations.

2. Evolving intellectual capacity

Digital transformation will require an evolution in leadership skills. By 2020, two of the top ten leadership skills will be cognitive flexibility and emotional intelligence. Aoun (2017), president of Northeastern University in Boston, considers that including these two characteristics in the list of the most important skills for 2020 highlights their importance. Leaders who can apply emotional intelligence and cultural awareness, demonstrating critical thinking and analysis, will be at the forefront of digital transformation and the Fourth Industrial Revolution.

3. Consider the resource dynamics

Project Managers should adopt the idea that the project teams that execute the strategy will not only be composed of traditional resources. Teams can be composed of existing and new talent, being multifunctional and using advanced robotics and computing systems. Project Managers will need to create teams with a balance of native knowledge and new experiences. In addition, the emphasis will be on open-mindedness, cognitive skills and emotional intelligence. These qualities will be much sought after by employers to make the efficient transition of available resources into a digitized workforce.

4. Refining emotional intelligence

Finally, the Fourth Industrial Revolution will require leaders to balance innovation and chaos with the stability of organizational processes. As more and more organizations adopt artificial intelligence and advanced robotics, leadership becomes less about people with titles and more about organic collaborative processes. This new dynamic requires that the management and leadership roles of a project overlap and are based on shared knowledge to mitigate organizational policies. The importance of relationships and emotional intelligence will continue to be critical for Project Managers as they facilitate the relationship, motivation and overall enthusiasm of organizations.

According to an article published by Melanima (2018), Project Managers must improve their skills and adapt to the needs of the market in order to be project managers in Industry 4.0. In the past, purely technical skills were essentially considered, but social skills are also essential for good professional performance and, increasingly, the ability to interpret data is important, stressing the importance of using Business Intelligence (BI), to allow you to have a greater knowledge of the internal and external environments, and thus increase the competitive advantage of organizations and the success of future projects. The role of project managers 4.0, in addition to having a technical profile within their area of competence, must have the ability to work on data (Method, Concept and Tool, data collection and modelling, using BI and/or Big Data), writing and mainly interpreting the data for decision making in a globalized corporate universe.

PPM leaders will apply more diverse combinations of PPM tools, capabilities and consulting services to support the needs of today's enterprises. Scaling digital business requires PPM leaders to adopt new approaches to strategic planning and execution and drive successful business transformation initiatives and programs. PPM leaders must adopt simplified ways to use multiple types of PPM tools to support both decision making and execution without introducing technology redundancy. The latest digital trends are presenting some clear challenges to the PPM market, and these challenges have yet to be met. There are new, emergent approaches to both strategic planning and execution requiring more innovative PPM technology. Demand for the latest digital technologies (e.g., artificial intelligence and robotic process automation in all enterprise software markets is also applying pressure to providers in the PPM market (Henderson et al., 2019).

According Henderson et al. (2019), digital technology challenges for the PPM market include the following issues:

1. Strategy-to-execution alignment and management

The alignment with the organization strategy is very important, and it is also mentioned by KPMG (2019), IPMA (2019), Bolick (2019) and PMI (2019). This is an important success factor for new projects, and it is also very important that stakeholders are involved and very close to the project;

2. Standardized enterprise portfolio decision making connected to diversified execution and delivery

The market shows us clear distinctions between standardizing strategic portfolio decision making and management and diversifying execution methods and approaches based on time for value. Continuous delivery is driving more PPM leaders to connect aligned strategic business investments with diversified, changing delivery focused on time for value creation (Henderson et al., 2019);

3. Continuous change

We are living in a globalized world with fast technology evolution, so Project and Porfolio Managers must be focused to working on a continuous change perspective. The PPM is a very important agent to allow companies to be aligned with innovation and evolution, maintaining a diversified offer without concentrating on just a few items, as those that do not evolve are unlikely to survive. The Project Manager has an important role in this respect. Bolick (2019) mentioned the importance of promoting agility and change, related with Project Manager as agents that respond to digital transformation. There were many known companies that disappeared because of lack of innovation. Take, for example, the case of Kodak, a large American multinational in the area of photography, which, by not investing on the digital, keeping its bet on traditional film, ended up disappearing from the market. Therefore, innovation is fundamental in a context of an increasingly global economy and the need to evolve to levels of greater competitiveness (Cabeças, 2018);

4. Supporting the shift from project-based management to digital-product-based management

The shift from project-based management to digital-product-based management is already a reality. This implies a need to continue to evolve towards collaborative delivery teams and it is necessary to give support resourced digital product management (Henderson et al., 2019). Digital-product-based management will bring advantages over the competition that will continue to bet only on a traditional project-based management logic;

5. Funding and resourcing agile investments at the portfolio level

The evolution of technology and rapid change is leading companies to make strong investments in digital and agile transformations, in order to achieve an expected result. For this to happen, business and technology teams need to be closely connected and aligned, and these investments must be considered from a portfolio perspective;

6. Funding and resourcing digital products at the portfolio level

Concerning funding and resourcing digital products, it is necessary to adapt the PPM mindset and culture to a global perspective of portfolio level oriented to digital products. As referred by Henderson (2019), we will have more organizations with enterprise project, program or product management office (PMO) focused on integrating digital products and programs;

7. AI-enabled PPM technology, including conversational AI and machine learning (ML)

PPM leaders try to find modern technologies to optimize and support the new roles, responsibilities and delivery methods of their PPM function. Applying AI to PPM-enabling technologies and areas appears to be a promising answer to this struggle, and yet the PPM market is in an embryonic stage as it relates to AI-enabled PPM (Henderson et al., 2019);

8. Robotic Process Automation - enabled PPM technology

> Demand for the latest digital technologies as robotic process automation is also applying pressure to providers in the PPM market (Henderson et al., 2019).

PPM capabilities identified as essential or critical, also mentioned by Henderson et al. (2019), include the following items:

- Project demand management;
- Project planning and management;
- Time management;
- Resource management;
- Resource capacity planning;
- Project portfolio management;
- Project collaboration;
- Program management;
- Reporting services;
- Security and user management;
- Integration;
- Usability.

As mentioned by the same authors, risk management and change management are also important capabilities but are not specifically measured in our PPM Critical Capabilities research as major items, but they are covered as underlying capabilities of other capabilities included in the previous list.

Because new projects will produce high impacts in society and in environment, it is recommended that Project Managers follow the recommendations of the Global GPM, in terms of respect for the 5 "P's". We are living in a world increasingly globalized, in which resources are limited, such as drinking water, coal and sand, that are threatened by their overuse, poor distribution and by climatic factors. The increase in pollution and the global planet warming must also be considered as a very serious concern. In a recent estimate by the Global Footprint Network, to maintain the same current consumption pattern, we would need to have 1.75 planet Earth, but we only have one.

4. Conclusions

We are going through a phase of great transformation in everything related to technology, the way business is conducted and how work is carried out. The availability of technologies, using artificial intelligence, Internet of Things, Big Data and Robotic, will continue to enhance the creation of new products that tend to improve the efficiency of humans, society, and organizations. The fourth industrial revolution causes changes in the labour market are expected, with the disappearance of some more routine and manual jobs (mainly in industry and agriculture), especially in jobs that require less qualifications, while other jobs will be created, namely associated with the creation, maintenance and administration of new technologies, as well as jobs related to creative intelligence, organizational manipulation, or social intelligence.

Though Industry 4.0 provides benefits, human freedom and confidentiality need to be maintained, special attention should be given to the new ethical issues that arise. Regulation plays a fundamental role in this respect, as well as the correct individual and organizational use of technologies, so that they act as facilitators to individuals and organizations rather than make humans slaves to these technologies. Grey (2016) predicted that solving complex problems, critical thinking, and creativity are the most important skills needed to face the Fourth Industrial Revolution. Emotional intelligence and cultural awareness must also be considered as strongly associated to technical skills.

In the recent period of the covid-19 pandemic, the Fourth Industrial Revolution continues to advance, but now at a faster pace, forcing the anticipation of strategic and operational decisions on the use of artificial intelligence, advanced robotics, big data and business intelligence. The use of new technologies in the implementation of telework already allows for a significant number of employees of companies in the services area to work from home. Today, a Project Manager is already able to manage projects without being physically present, using Project Management support tools and videoconferencing systems, which allow for project planning and control at a distance and conducting online contact sessions with the project participants. In the industry, with intelligent robotics, many tasks can also be performed without workers being physically present. In the health sector, the evolution has been remarkable, for example, imaging exams can already be diagnosed online by doctors working from their homes, through their personal computers, the same being also true for surgical intervention supported by robotic systems. There are studies and experiences on computerized prosthesis commanded by the human brain being created and intelligent artificial organs being produced. Intelligent buildings, offices, private homes, vehicles and agriculture are other examples of recent evolution.

The Fourth Industrial Revolution implies changes in the way projects are managed and requires Project Managers to adapt to the new needs and expectations of the sector, responding to the development of new technologies. PMI (2019), highlights that the approaches used by PMTQ Innovators Versus the PMTQ Laggards, using a variety of project management approaches, lead to better results, considering that organizations which are PMTQ Innovators are better prepared to take the lead on project outcomes. Their projects are more likely to meet their original goals and be delivered on time and within budget while reducing scope creep and outright failure, leading to success.

Project Managers are agents of digital transformation and will have to be aligned with their organization's strategy. More than technical specialists in the area of their projects, Project Managers must be able to take advantage of the data and information available using Business Intelligence and Big Data. They should also use the new capabilities offered by artificial intelligence tools to support all Project Management activities, stressing the importance of QTGP. There are, therefore, new technological challenges which Project Managers must meet, but they cannot lose sight of the importance of the five "P's", People, Planet, Prosperity, Processes and Products, taking care of the planet, following ethical and sustainability principles, and the future is already happening.

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INTELIGENCIA ARTIFICIAL Y MEDICINA

La necesidad de modelos interpretables

Artificial Intelligence and Medicine: the Need for Interpretable Models

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KEY WORDS

Artificial Intelligence
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Covid-19

ABSTRACT

The pandemic has provided clear examples of the potential of AI for the health sector, as well as some of its issues, largely derived from the use of black box models. In some cases, there are no reasonable alternatives, as in image and speech processing. However, in many other instances it would be more profitable to try to focus the developments on Interpretable AI, which could be used more directly for the confirmation of knowledge or for the generation of new hypotheses that can be tested with subsequent experiments.

PALABRAS CLAVE

Inteligencia Artificial
Ciencias de la salud
Sistemas de Diagnóstico
Modelos Predictivos
Caja negra
IA Interpretable
Covid-19

RESUMEN

La pandemia ha proporcionado ejemplos claros del potencial de la IA para el sector de la salud, así como algunos de sus problemas, en buena parte derivados del uso de modelos de caja negra. En algunos casos, no existen alternativas razonables a los modelos de caja negra, como en tratamiento de imagen y voz. Sin embargo, en muchas otras situaciones resultaría más provechoso intentar centrar los desarrollos en la línea de la IA interpretable, que podrían ser aprovechados de manera directa para la confirmación de conocimiento o para la generación de hipótesis nuevas que puedan comprobarse con experimentos posteriores.

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GLOBAL KNOWLEDGE ACADEMICS

1. Una emergencia sin precedentes

La pandemia ha generado una emergencia sin precedentes que se ha materializado no sólo a nivel médico sino también científico: el conocimiento es necesario para apoyar la toma de decisiones y hemos necesitado generarlo a una velocidad mucho más rápida de la que estamos acostumbrados.

La inteligencia artificial (IA) ha demostrado ser una herramienta de valor incalculable para generar nuevo conocimiento y herramientas de utilidad inmediata. Además, la situación actual ha dejado patente que contar con datos fiables y transparentes es imperativo para poder apoyar la toma de decisiones técnicas y políticas.

La IA trabaja sobre los datos y construye modelos de manera mucho más rápida que los basados en la experiencia humana. Esta necesidad de velocidad se ha visto también reflejada en la tremenda aceleración que ha experimentado la generación de conocimiento. Tanto es así, que esta época ha sido denominada por algunos el "auge de los preprint", refiriéndose a los artículos científicos que se difunden, dada su urgencia, cuando aún no han superado el proceso de revisión por pares previo a su publicación.

La velocidad y el aprovechamiento de los datos según se generan, que tanto necesitamos en tiempos de crisis, son precisamente las principales ventajas de la IA. Este artículo repasa algunos de los desarrollos más interesantes en este contexto y extrae las lecciones más importantes sobre la IA y sus oportunidades y limitaciones en el contexto de las ciencias de la salud.

2. Nuevas aplicaciones de la IA en las ciencias de la salud

Una de las primeras aplicaciones de la IA en este contexto fue la creación de pruebas diagnósticas en los momentos en los que no existía disponibilidad de pruebas PCR. Se consiguió desarrollar alternativas a la PCR que funcionaban a partir de imágenes de tomografía de tórax con una alta fiabilidad de diagnóstico (Ardakani, Kanafi, Acharya, Khadem, & Mohammadi, 2020).

El rastreo de contactos ha sido otra área en la que la IA ha realizado aportaciones significativas. Más de 36 países han empleado herramientas digitales para el rastreo de contactos con relativo éxito (Lalmuanawma, Hussain, & Chhakchhuak, 2020). En estas aplicaciones, la IA complementa el rastreo manual, en ocasiones introduciendo elementos de teoría de grafos.

La IA nos ha ayudado también en la búsqueda de tratamientos efectivos para la Covid. Desde hace tiempo se utilizan las técnicas de simulación molecular para identificar fármacos que podrían tener interacciones con una sustancia dada (por ejemplo, con las proteínas de la espícula del virus). Las técnicas de simulación ayudaron a identificar moléculas como el Remdisivir y el Antazanavir como posibles fármacos para la lucha contra la Covid (Beck, Shin, Choi, Park, & Kang, 2020). Estos fármacos no se aceptan de manera directa, sino que se someten a ensayos clínicos específicos. La IA nos ayuda, así, a centrar los esfuerzos en opciones interesantes sin dejar de cumplir los procedimientos establecidos.

El análisis de los síntomas para predecir la evolución de los enfermos ha sido otro contexto en el que las aportaciones de la IA han resultado insustituibles. Por ejemplo, en una serie de proyectos en los que he tenido el placer de participar, la IA ha identificado los principales factores de riesgo que incrementan la necesidad de ingreso en cuidados intensivos (Izquierdo, Ancochea, Soriano, & Savana COVID-19 Research Group, 2020), las diferencias que manifiesta la enfermedad entre hombres y mujeres (Ancochea, Izquierdo, Savana COVID-19 Research Group, & Soriano, 2020) o las interacciones entre la Covid y la enfermedad pulmonar obstructiva crónica (Graziani et al., 2020).

También han emergido estudios en los que el análisis de datos ha arrojado conclusiones contradictorias o confusas, como es el caso de las asociaciones entre la gravedad de la enfermedad de Covid y el grupo sanguíneo de los pacientes (Zietz & Tatonetti, 2020).

En todas estas aplicaciones -y otras muchas- queda patente el potencial de la IA y el análisis de datos para apoyar el desarrollo de conocimiento nuevo de manera rápida, aprovechando su capacidad de desvelar los patrones que aparecen en los datos.

3. ¿Puede la IA generar conocimiento médico?

Como decíamos, la IA es capaz de identificar en los datos patrones que ya sean conocidos por la comunidad científica (con lo cual, pueden confirmar este conocimiento) o desvelar patrones nuevos, como ha venido sucediendo en incontables aplicaciones de diagnóstico automático o de modelos predictivos aplicados a la salud.

Sin embargo, es necesaria la prudencia al hablar de generación de nuevo conocimiento: la IA puede como mucho, desvelar correlaciones, y corresponde a los expertos en cada problema particular establecer si estas correlaciones tienen como base un fenómeno clínico conocido, si responden a un fenómeno previamente desconocido pero razonable y que puede estudiarse a través de experimentos posteriores o si se deben a defectos de los datos de entrada (como podría ser el caso, por ejemplo, en el estudio sobre Covid y grupo sanguíneo). Estas tres situaciones diferentes aplicarían tanto a sistemas de diagnóstico como a modelos predictivos y aplicaciones de gestión.

4. Las cajas negras

Establecer en cuál de esos tres supuestos anteriores nos encontramos no es posible en el caso de los algoritmos denominados, de caja negra, en los que estas correlaciones no se hacen explícitas: el algoritmo (por ejemplo, una red neuronal) se entrena a partir de unos datos de entrada y devuelve una predicción para cada nueva instancia que le sea presentada. Sin embargo, no incluye ninguna explicación de la predicción que pueda utilizarse como punto de partida para comprenderla.

Esto resulta problemático en todo contexto en el que las decisiones que se tomen basadas en los modelos revistan alguna importancia, como es el caso comúnmente en las aplicaciones médicas. Para poder utilizar una herramienta, y mucho más para delegar una decisión, hemos de poder confiar en lo que nos comunica. ¿Cómo podríamos confiar en lo que no podemos comprender? Me refiero aquí a comprender el resultado complejo de la aplicación del código, aunque los mecanismos en esencia sean extremadamente simples. El resultado de la IA es complejo en el sentido en el que las ciencias de la complejidad aplican esta palabra (Mitchell, 2009): un sistema complejo es un sistema donde unas pocas reglas simples e interacciones de las partes dan lugar a fenómenos que no podemos deducir a partir de estas reglas. Esta emergencia, en el sentido de Chalmers (precisamente, la aparición de fenómenos inesperados (Chalmers, 2006)) hace que sea imposible anticipar el resultado del código a partir del mismo.

Sin embargo, los algoritmos de caja negra sólo nos dejan examinar eso: su código. Y esto presenta graves problemas. Si no sabemos cómo el algoritmo determina una decisión, ¿cómo podremos confiar en ella? Muchos, precisamente, desconfían de la IA por este motivo. Creo que esta desconfianza está plenamente justificada. Dos motivos resultan, en la práctica, los causantes de la mayoría de los problemas relacionados con la aplicación de sistemas de control delegado: el sobreajuste y el sesgo algorítmico.

5. Sobreajuste y sesgo algorítmico: dos problemas que la medicina no puede tolerar

En el sobreajuste, los datos que se le proporcionan a la máquina no son suficientes como para poder generalizar. Hemos de recordar que el aprendizaje automático extrae patrones en los datos que podríamos asemejar a "ejemplos de problemas resueltos" y que después aplica esas reglas a nuevas instancias del problema. Si los ejemplos que se le han proporcionado son suficientemente diversos y similares a los problemas a los que se aplicará después, el algoritmo probablemente funcionará bien. Sin embargo, en muchas ocasiones el algoritmo recibe menos datos de los que serían necesarios, con lo que, como un mal estudiante, acaba aprendiéndose los ejemplos de memoria, lo cual produce consecuencias desastrosas cuando intentamos generalizar. Si diseñamos un algoritmo para distinguir gatos de perros, pero todos los perros que aparecen en los datos de entrenamiento son blancos y los gatos son negros, el algoritmo probablemente inferirá que los animales blancos se llaman perros y los negros se llaman gatos. Si se le muestran fotografías que no correspondan a estos colores, generalizará de manera desastrosa. Si pudiéramos acceder a las reglas que ha derivado el algoritmo sería posible auditarlas, pero esto no está dentro de nuestras posibilidades si trabajamos con una caja negra. Aún así, existen técnicas más o menos sofisticadas para intentar detectar posibles problemas de sobreajuste, pero por definición son difíciles de detectar.

De la misma manera, es posible que los sesgos presentes en los datos hagan que el algoritmo se base en variables que consideraríamos inadecuadas, lo que identificaríamos con el problema de sesgo algorítmico. Es bien conocido el ejemplo de ProPublica, la empresa que desarrolló un algoritmo de tipo caja negra para predecir la reincidencia criminal en los presos estadounidenses. Este algoritmo se lleva aplicando durante años para decidir si a los presos se les concede la libertad condicional. Tras análisis detallados de sus predicciones, se vio que una de las variables principales empleadas por el algoritmo era la raza: los presos afroamericanos, independientemente de su historial, recibían predicciones peores que los blancos. Esto se debía, al parecer, a la base de datos que se había empleado para entrenar al algoritmo: los presos de color de esos datos tenían una peor tasa de reincidencia. Otro ejemplo reciente, también relacionado con la raza, es el que emergió en una red social que filtraba con mucha más frecuencia las fotos de mujeres de color como contenido inapropiado. Al parecer, el algoritmo se entrenaba con fotografías publicitarias, por una parte, y con contenido pornográfico por la otra. Este último era mucho más racialmente diverso que la publicidad, lo que llevaba al algoritmo a asumir con más facilidad que la foto de una mujer que no fuese blanca correspondía a contenido inaceptable.

El sobreajuste y el sesgo algorítmico pueden ser extremadamente dañinos en cualquier contexto, pero en las ciencias médicas se vuelven intolerables. El nivel de fiabilidad que se le pide a los desarrollos médicos refleja la importancia de las decisiones que de ellos se derivan.

6. ¿Es posible superar las cajas negras?

Tanto el sobreajuste como el sesgo algorítmico podrían solventarse – o, al menos, detectarse, lo cual sería la primera etapa hacia su solución – si los algoritmos nos dejasen *ver* las reglas que infieren, si dejasen de ser cajas negras. Son muchos los que piensan que únicamente los modelos de caja negra alcanzan desempeños aceptables: se asume que sólo los modelos muy complejos, demasiado complejos como para poder comprenderse, son los que tienen alguna posibilidad de funcionar adecuadamente en los problemas reales. Sin embargo, esto no es cierto en todos los casos, ni siquiera en su mayoría. Pese a que en algunos casos (principalmente, el procesamiento de imagen o de sonido) sólo tienen aplicación los modelos especialmente complejos como las redes neuronales convolucionales y otras técnicas del espectro del aprendizaje profundo, en muchos otros problemas es posible desarrollar modelos transparentes. Cada vez recibe más apoyo la idea de la IA Interpretable (Molnar, 2020) . La hipótesis de base es que no existe un solo modelo que pueda realizar adecuadamente una tarea, sino que son posibles muchos modelos diferentes, con niveles de complejidad dispares. Algunos de ellos serán tan simples que sus reglas pueden expresarse de manera explícita (por tanto, no son cajas negras).

Por ejemplo, Cynthia Rudin desarrolló una alternativa a la caja negra "racista" de ProPublica (Rudin, 2019). El sistema era un esquema simple de puntuaciones en los que consideraba variables transparentes como la edad, el número de crímenes y de crímenes violentos cometidos en el pasado, con una puntuación determinada para cada posible valor. Este modelo tiene un poder predictivo muy similar a la caja negra de ProPublica, pero es completamente transparente. Los modelos basados en puntuaciones, las regresiones logísticas o los árboles de decisión son técnicas dominadas por todos los ingenieros que trabajen en este contexto, pero no son las más aplicadas porque generan una sensación de simplicidad (en el mal sentido), de falta de sofisticación cuando se las compara con las cajas negras. Parece como si fuésemos un mago que no quisiera revelar sus trucos – o sus errores.

En los últimos trabajos en los que he aplicado técnicas de IA a un contexto de medicina he aprendido muchas cosas, pero una es la más importante: sólo es válido el modelo en el que podemos confiar, y sólo podemos confiar en algo que comprendemos y que además *tiene sentido* cuando lo ponemos en relación con la experiencia previa y el sentido común.

No puedo dar por válido un modelo que cuantifique el riesgo de que un paciente de Covid ingrese en UCI según la provincia que habita (¿o quizá sí?), o que prediga que padecer de diabetes disminuye el riesgo, o que los pacientes de 79 años tienen un riesgo decenas de veces mayor que los pacientes de 80 años y medio. Todos esos son resultados que pueden aparecer en un modelo, y que pueden ser matemáticamente correctos en el sentido de adaptarse adecuadamente a los datos que reciben. Sin embargo, no son válidos porque no se basan en reglas que tengan sentido clínico (es decir, para una persona con conocimiento clínico). Este "ojo clínico", sobre el que reflexionaba Federico de Montalvo (de Montalvo Jääskeläinen, 2018) debe exigir recibir información que sea capaz de juzgar. Si en vez de los ejemplos anteriores encontramos que la taquipnea o respiración acelerada es la principal variable predictiva, el modelo pasa a ser una ayuda que da una forma concreta a la experiencia existente sin contradecirla, en la que asumir un cierto grado de generalidad estará dentro de lo razonable y que, desde luego, no realiza inferencias indeseables. Los patrones en los datos son simplemente esto, correlaciones, y es sólo el experto el que puede relacionar esas correlaciones con fenómenos conocidos o con nuevas hipótesis comprobables.

7. Conclusiones: Aprovechemos el potencial de la IA en las ciencias de la salud

La IA tiene un enorme potencial para apoyar las ciencias de la salud, desde el diagnóstico, los modelos predictivos o las aplicaciones a la gestión. Sus principales puntos fuertes, como la crisis del Covid ha manifestado, son la rapidez y el aprovechamiento de los datos.

Sin embargo, los modelos de caja negra tienen una aplicación limitada en las ciencias de la salud, debido a que no son capaces de generar la confianza necesaria para este tipo de aplicaciones. Esta falta de confianza está justificada en los errores (como el sobreajuste y el sesgo algorítmico) que pueden derivarse de problemas en el desarrollo de los modelos o en la preparación de sus datos de entrada.

En algunos casos, no existen alternativas razonables a los modelos de caja negra, como en tratamiento de imagen y voz. Sin embargo, en muchos otros problemas es posible desarrollar alternativas transparentes. En general, resultaría mucho más provechoso intentar centrar los desarrollos de IA en el sector de la salud en la línea de la IA interpretable, que podrían ser aprovechados de manera directa para la confirmación de conocimiento o para la generación de hipótesis nuevas que puedan comprobarse con experimentos posteriores.

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THEORY OF MIND

From Artificial Intelligence to Hybrid Intelligence

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ABSTRACT

Philosophy of mind has long ceased to be, if indeed it ever was, the exclusive domain of philosophers. In contemporary thought there is increasing interest in these matters from the point of view of technology. This paper gives a critique of the ideas of Ray Kurzweil and briefly reviews some of the recent trends in the treatment of these questions.

GLOBAL KNOWLEDGE ACADEMICS

One of the most common metaphors to speak of the mind is, without a doubt, that of the computer, or, more generally, the machine. This immediately shows that, at least in the sphere of folk psychology, we take for granted that thinking is an action and that, as with all actions, thought has an executant who uses an instrument or a tool —incidentally, we should remark that if we regard thought as an action it is because, in some way, thought take place through time, that is, because we are aware that time passes and we pass with it. Although we will not dwell on this observation, which we think is an essential one, we will try to extract some benefit from it later.

The image of the machine elicits a series of analogies that may have seemed useful and stimulating in order to understand that which is generally called the mind, especially when, since modernity, the Aristotelian notion of soul as the form of the body was abandoned. Although in its Cartesian origins the mind was primarily a conscious one entirely distinct from matter, very soon the view took hold that the thinking substance is just another product of the bodily machinery, and also relatively soon analogies began to be suggested that were supposedly enlightening as to its function. Whatever may have become of this idea, what we want to emphasize is that the philosophy of mind that has been predominant since the mid-20th century has assumed, very frequently, that the mind is a certain kind of device, a device that mediates strangely between an objective reality that is nevertheless in some way ungraspable, and a subjective reality that ultimately becomes objectivized in various forms or modes such as language, logic or science. Thus, somewhat surreptitiously, it was possible somehow to translate the *problem of consciousness*, which is rather intractable, into a sort of *problem of intelligence*, and to assume thereupon that if we could create a machine capable of thinking the way we seem to do it, there would be no fundamental objection to saying not only that the machine thinks, but that it has as much consciousness as one needs to be around in this world. In other words, in order to dodge the evident elusiveness of consciousness, the alternative taken was, as might be expected, to elude its study. It was then possible to speak of artificial intelligence and the mind-machine problem. The great advantage of this approach was that it presented scientists with a sufficiently large work programme to forget the reasons that might impel them to “waste time” with *metaphysical* enigmas. If, after all, it could be said that scholastic cosmology finally died at the hands of the telescope, it was reasonable to expect that *spiritualism*, to call it such, would end up dying at the hands of computer science. Philosophy of language was then to cleanse the mortal remains of the *ghost in the machine*, which is more or less what *eliminative materialism* has tried to do, as have in general all doctrines that have thought that an intensive verbal treatment[1] could remove from the horizon the *hard problem,*[2] as it has been called, along with other ones that tend to look easier than they really are.[3]

At any rate, there was an almost Freudian omission in this, let’s say, programme; a very peculiar aspect of the matter was overlooked, a deficiency that has been pointed out recently by Roger C. Schank, [4] namely, that it is nigh impossible for us to imitate what we do, if we do not know how we do it. Indeed, because it is a big

[1] Something along these lines could be said also of those who insist on finding different models of approach, as if the problem could be reduced to a flaw in the logic of how it is formulated. We could regard as a suggestion of this sort the one made by Alva Noë (https://philosophy.berkeley.edu/noe) in a very interesting interview in Edge (which can be read at http://www.edge.org/3rd_culture/noe08/noe08_index.html), according to which the mind is not something that happens in the brain, because it is not *inside* of us, it is something we do.

[2] I believe David Chalmers (1995) and (1996) was the first to use this terminology.

[3] Putnam (1999:13) observes, for example, that “many philosophers want to dismiss traditional problems in the philosophy of perception as if too much time had already been wasted on them and as if we were simply beyond them now.”

[4] “We can speak properly without knowing how we do it. We don't know how we comprehend. We just do. All this poses a problem for AI. How can we imitate what humans are doing when humans don't know what they are doing when they do it? This conundrum led to a major failure in AI, expert systems, that relied upon rules that were supposed to characterize expert knowledge. But, the major characteristic of experts is that they get faster when they know more, while more rules made systems slower”. (https://www.edge.org/response-detail/11038.)

thing to forget that we do not know –in fact we have no idea– what it is we are doing when we think, or how we do it. Incidentally, this ignorance is not specific to thought, since we also have no any idea whatsoever –even though many people believe otherwise– what it is we do when we speak, or how we do it, or what we do when we move our heart, or when we breathe, although it is fair to admit that we seem to know a little more about the latter. In overlooking this, no doubt crucial, aspect of the matter, what the mind-machine programme did, in a sense, was to imitate the *product* of our action, not the *way to produce it*.

There is no good reason to brush aside what we might call a *primary* or, if you will, *naïve dualism*. It is quite useless to waste saliva trying to change the names of things in the hope of covering the problem or making it disappear, and there are no sufficiently powerful reasons that would impel us inevitably to accept some form or other of physicalism, be it physical, biological or digital. Nevertheless, we the authors have never had difficulty in recognizing that dualism is not a satisfactory solution either; it is just the best way to refer to a question, or family of questions, that are on the boundary of our view of the world, no less; a problem Schopenhauer named, brilliantly, the *riddle of the world*.

1. Artificial intelligence: faith in technology as a *cultural* factor, with a brief Ortegan *excursus*

When everything seemed to indicate that the failure of the prophecies by the first AI gurus had removed from the agenda the question of machine thought, one of today's great software creators has brought it back to life with his ideas, which not only renew the promises of what was called strong AI, but they complement them, concretise them and endow them with a rather peculiar halo of mysticism. We are referring to Ray Kurzweil[5], one of the best-known gurus of Silicon Valley (he was one of the creators of the so-called OCR programs and the software that can convert text to speech), who is convinced that very soon it will be possible to attain a personal and bodily quasi-immortality (particularly bodily, through medication). Our man has agitated the scene with his publications, conferences, and even a documentary film about what he calls *spiritual machines* and the imminence of the perfect synthesis of minds and machines.

Kurzweil (1999:123) draws inspiration explicitly from the human genome project, launched in 1991, suggesting that just as it has become possible, at least in theory, to *map* the entire human genome, it will be possible to map the human brain, synapse by synapse. A wide range of very interesting possibilities will then lie open before us. For instance, we could save our personal memory in more robust files that would be immune to the well-known phenomenon of memory modification; we could *copy* our minds, aggregate them, erase them (partially, it is to be presumed); that is, we could do with our minds everything that we can do now in almost completely routine fashion with our computer files.

The connotations of Kurzweil's work suggest that we consider it from a broader perspective than that of theory of mind. If we leave the somewhat confined field of philosophy of mind, perhaps Kurzweil's ideas should be seen as a contribution to a current that has acquired some notoriety in the medical field known as *enhancement medicine* (or *enhancement technology*), which Juengst (1998:29) has defined as the set of "interventions designed to improve human form or functioning beyond what is necessary to sustain or restore good health." Technological enthusiasm is not a new phenomenon, but advances in the so-called NBIC domains (*nanotechnology, biotechnology, information technology, cognitive sciences*) have encouraged this sort of propositions, to the extent that enhancement medicine itself could well be superseded by what has already been called transhuman medicine or medicine for transhumanist enhancement (Wolbring, 2005). For the proponents of this new medicine, human physical and mental qualities are indefinitely perfectible. The yardstick of normality should no longer be the empirical mean but the "transhuman" state reached by virtue of applying

[5] The reader can visit his very comprehensive webpage, at http://www.kurzweiltech.com/aboutray.html.

specific technologies[6]. From this point of view, Ray Kurzweil's ideas, according to which the moment is near when humanity will transcend its biological limitations and reach a symbiosis with machines, which in turn could be regarded as spiritual, would mean the elimination of all relevant distinction between nature, humanity and technology.

What is thus brought into play is a very nebulous and complex question, one that allows us to make an immediate connection between philosophy of technology and philosophy of mind. More generally, Putnam (1999:69) was absolutely right when he wrote that "a nice allocation of philosophical problems to different philosophical 'fields' makes no real sense. To suppose that philosophy divides into separate compartments labelled 'philosophy of mind,' 'philosophy of language,' 'epistemology,' 'value theory,' and 'metaphysics,' is a sure way to lose all sense of how the problems are connected, and that means to lose all understanding of the sources of our puzzlement."

In any case, we would like to observe that one of the first authors to reflect on the importance of technology to give meaning to human life was actually Ortega y Gasset, and he did so very brilliantly. Ortega was able to see in technology at least two very profound and interesting dimensions which he examined with great insightfulness, although with his characteristically wandering focus. On one hand he thought that technology could act as a gendarme of the spirit that subjects imagination and literature, its most frequent ally, to a regime of asceticism and continence. But, secondly, he also realized that technology evinced a capacity for invention that is part of the essence of man, and not merely a choice. In Ortega's analysis these two dimensions of technology meet at a relatively unstable point of equilibrium because fantasy plays an essential role in both: in the former, as a force that must be contained; in the latter, as the key to the meaning of technology.

Ortega (1996:114) wrote that, far from living on Earth, man actually lives on beliefs, on a philosophy, but in such a way that, in spite of it, he lives in a state of essential dissatisfaction, of maladjustment, perhaps because he is too aware of the limitations of his beliefs. And so, man starts out by constructing his own way of being in the world. Man's own way of inhabiting cannot be reduced to a kind of natural destiny; it is a discovery, a formula: this was the idea that Ortega presented in his lecture to the German architects in Darmstadt, a brilliant piece which nevertheless he bemoaned somewhat bitterly. He said there (1996:107), literally: "Man is, essentially, dissatisfied, and this -*the dissatisfaction*- is the highest quality man possesses; precisely because he tries to have things he has never had. This is why I often say that such dissatisfaction is like love without a lover or like a pain I feel in members I have never had."[7] This characterisation of man is debatable, but there can be little doubt that what Ortega asserts in some way explains both the behaviour of the *mass man* and that of the most demanding and eminent philosopher, typically unsatisfied with any theory.

Ortega had already used very similar ideas in *The revolt of the masses*, showing how the *mass man* experiences the absence of standards and coercion as an invitation to live his own way, to prevail (1962:180). "If the traditional sentiment whispered: 'To live is to feel oneself limited, and therefore to have to count with that which limits us,' the newest voice shouts: 'To live is to meet with no limitation whatever and, consequently, to abandon oneself calmly to one's self. Practically nothing is impossible, nothing is dangerous, and, in principle, nobody is superior to anybody.' This analysis constitutes the acknowledgement of an important historical change in which the technological civilisation has had a predominant role: in the past, life for the average person was fraught with difficulties, dangers and want of every kind, and this made it necessary to obey the law, to embrace deeply the observance of an extensive body of norms. But today's world presents itself to us -at least in appearance- as a safer, more abundant place, where we are not so compelled to respect social norms; where virtually no one challenges our right to live according to our own rules or our right to satisfy our desires, although it is surely

[6] José Luis Puerta and I have considered the medical aspect of these matters more specifically in González Quirós (2009c).

[7] Excerpts from Ortega (1962) translated for this paper from the original in Spanish.

the case that the passion to regulate, inseparable as it is from any form of power, has moved to other areas, endeavouring to conceal its presence in order to confound us more. This general impression that every individual has about the world he chances to live in eventually turns into an invitation to aspire, to lose his fear of the impossible.

Of course, Ortega was aware of the significance technology has in the fate of humankind, as well as the risks it can engender, and so he wrote (1996: 55), "perhaps the fundamental disease of our time is a crisis of desires, which is why all the fabulous potentiality of our technology seems as if it were of no use to us." Nevertheless, Ortega was able to see with great clarity that technology is not merely man's adaptation to the world, but, more properly, it is the creation of a new world, as, according to him, man is ill-adjusted to nature and desires a world of his own.

At the time of Ortega's death, it was impossible to foresee almost any of the advances which today we regard as decisive when considering the relationship of man with his environment and weighing the effects of technology on human society. However, he was able to see how a new and paradoxical horizon of confrontation between nature and technology was taking shape, when he wrote, "technology's victory aspires to create a new world for us, because the original world does not suit us, because we have fallen ill in it. The new world of technology is, therefore, like a gigantic orthopaedic device… and every technology has this marvellous and —as everything in man— dramatic tendency and quality: that of being a fabulous and great orthopaedic apparatus."

Returning to Kurzweil, we must put into today's context his promise that an unprecedented augmentation of our intellectual abilities awaits us, if we manage to coexist with those spiritual machines he speaks of, in a context in which, for example, we know there are orthopaedic legs that make it possible to run faster than with natural ones. Kurzweil believes that what technology can do with the body it will be possible to do also with the mind: a virtually endless improvement of its capacity and reliability, a reform of its glaring deficiencies, in light of the abilities our self-knowledge allows us to dream of.

Kurzweil's assertion implies that in the field of minds and machines, of biological brains and computers, *Ortegan orthopaedics* will be vastly surpassed by a synthesis that will entail a veritable fusion, and, with it, the beginning of a new evolutionary phase for humankind. His position, which, aside from other opinions it may deserve, doesn't seem to see any difficulties beyond the technological, compels us to ask whether it is based on more than just a deliberately vague promise; on an extrapolation of dubious legitimacy.

We know very well that, at present, the human genome project has failed to meet even a small fraction of the hopes that some of its proponents aimed to arouse, and so, although it is not a good approach to tie an argument to a failure that may cease to be so,[8] we must question whether there is any solid foundation on which to support Kurzweil's promises. Kurzweil maintains that the power of ideas to transform reality is growing at increasing speed, and he proposes a theory he calls "Law of Accelerating Returns" to explain how, according to him, technology and the evolutionary progress it feeds behaves as an exponential function (2005:3). When we are able to understand how we understand, when we can turn our intelligence into an object and obtain its "source code", we will be able to review it and expand it in completely new ways. Human life will be transformed irreversibly (2005:7), we will be able avoid many fatalities, we will have immortality very close at hand, and, at the end of

[8] It is all too common to laugh at prophecies of the past when they have not come true, but this is probably not a very intelligent attitude. It is interesting to note that this happens both when things that it was thought would happen don't, and when very important things do happen that no one was able to predict. Regarding the former case, it may be interesting to review the list of prophesies collected by the late Arthur C. Clarke (1999: 536ff). Although it does not fit the latter case exactly, it is very interesting to take a look at the roster of changes (albeit only as far as the culture industries are concerned) that have happened in the last forty years, compiled by the editor Mike Shatzkin (https://www.idealog.com/blog/stay-ahead-of-the-shift-what-publishers-can-do-to-flourish-in-a-community-centric-web-world). That something has not happened so far is not always enough reason enough to believe it will never happen.

the 21st century (2205: 30), the nonbiological portion of our intelligence will be –he says literally– trillions of times superior to mere human intelligence without external aids.

Whoever wants to find precise reasons for such stupefying statements should not waste time looking for them in the works of Kurzweil. We at least have not been able to find them. Our author relies mostly on such claims as that technological progress has always been exponential, or that the small (?!) genomic difference between chimpanzees and human beings –which according to Kurzweil (2005: 5) is of the order of a few hundred bytes– has not prevented us from creating technological wonders. And, of course, he embraces, without a hint of doubt, the conviction that the computational notion of the mind is entirely correct.[9]

Although rivers of ink have been spilled about what is meant exactly by computational theory of the mind[10], the idea, in essence, is that there is a basic and illuminating analogy between how *hardware* and *software* are related and how the brain (or *wetware*, as it is sometimes called) and the mind are. At heart, the computational model of the mind, as Carver (2007: 101) has pointed out, embodies and reinforces the functionalist analysis, assuming that the black box of the functionalist model is a computer.

At the same time, we can see functionalism, in a sense, as a *consequence* of the behaviourist analysis of mental phenomena; a rather heroic endeavour to avoid the difficulties and paradoxes of the intuitive notion of conscious mind, which some audacious philosophers, like Dennett, have not shied away from daring to undertake in order to eschew the threat of dualism. Thus, Dennett (1991: 430) has written: "if what you are is the program that runs on your brain's computer [...] you could in principle survive the death of your body as intact as a program can survive the destruction of the computer on which it was created and first run."[11] Kurzweil presumably goes beyond this assertion of Dennett's –although, as we see, he is not the first to do so– in assuming that we have something more than an illuminating theory available to us because, as his interpretation of Moore's well-known law predicts, we are on the verge of having technology powerful enough to allow us to move from hardware to the brain and software to minds, in the same way that we can move, biologically, from the mind to the brain and vice versa. To hold this view is to forget all the difficulties that philosophers have identified regarding such a conversion. It is surprising that it should be proposed to throw out of the window the body of problems that philosophers have analysed in this regard, without realizing how dangerous certain metaphors are when they are passed off as science. About "Functionalists who deny that knowing about the details of the brain will ever tell them *anything* useful" Francis Crick (1994:75) wrote that "[t]his point of view is so bizarre that most scientists are astonished to learn that it exists" (*Ibid*.). If we assume that, in the same way as, it seems, happens with neurons, we will make consciousness emerge when we find the organisational pattern that can make silicon think, we are saying something that can hardly be taken seriously. One of the fiercest criticisms of this idea comes from one of its very founders: Hilary Putnam. In one of his last contributions to this knotted question, Putnam (1999:86) maintains that, insofar as the

[9] This idea is not always shared by researchers in the field. We shall cite here the opinion stated recently by Noel Sharkey: "Roboticist Hans Moravec says that computer processing speed will eventually overtake that of the human brain and make them our superiors. The inventor Ray Kurzweil says humans will merge with machines and live forever by 2045. To me these are just fairy tales. I don't see any sign of it happening. These ideas are based on the assumption that intelligence is computational. It might be, and equally it might not be. My work is on immediate problems in AI, and there is no evidence that machines will ever overtake us or gain sentience." The full article can be accessed here: http://www.newscientist.com/article/mg20327231.100-why-ai-is-a-dangerous-dream.html?full=true.

[10] The discussion on the matter between Ray Tallis and Igor Aleksander (2008) can be viewed at https://link.springer.com/article/10.1057/palgrave.jit.2000128.

[11] We do not know if Dennet realises that this assertion could be taken, albeit only in some sense, as an updated version of the notion of soul as the form of the body, and that it may accommodate admirably well the idea, religious in this case, that the soul could very well survive the body, be eternal. We do not see much difficulty either, if we may continue with the diversion, in that a God capable of handling all the information (just a shade more informed than Laplace's demon) could restore our best bodily shape, in order not to leave us, so to speak, leading a ghostly existence.

computational property has not been given a determinate meaning, functionalism is science fiction erected on a misunderstanding. No one to date has managed to solve a poorly conceived problem, so the objection Putnam raises to reductionists can be equally valid for naïve approaches like Kurzweil's, who believes he can see clearly in the future that which he cannot understand now: "Saying 'Science may someday find a way to reduce consciousness (or reference, or whatever) to physics' is, *here and now*, saying that science may someday do we-know-not-what we-know-not-how" (1999:173).

Putnam further adds something particularly interesting: "Not only does rejecting reductionist pictures *not* entail abandoning serious scientific research but, in fact, it is those pictures that often lead researchers to misconceive the empirical problems" (1999:174). Putnam defends philosophy, which has all but disappeared from Kurzweil's writings, as in effect he embraces eliminativism, while not seeming to realise that not being a philosopher is not enough to avoid the problems, as, again in Putnam's words, "philosophical confusion reaches far beyond the studies of professional and amateur philosophers" (1999:175), and though "[m]any things deserve our wonder [...] the formulation of an intelligible question requires more than wonder" (1999:174).

2. On what Kurzweil seems to forget

Besides the abundant and recurrent criticism philosophers may have directed toward the so-called strong AI programme, its failure lied, essentially, in a glaring inability to create something like a living consciousness, and also in the very limited success achieved in imitating intelligent activities that early pundits thought were very simple. Although it may be somewhat unmerciful, I cannot resist citing again a few statements I included in another book[12] to characterise what I called *cyberphilosophy*. In its first steps, some of the more conspicuous proponents of AI proclaimed that their work could be regarded as, at least, the third greatest event in the history of humankind. Marvin Minsky declared in LIFE magazine in November 1970: "In from three to eight years we will have a machine with the general intelligence of an average human being. I mean a machine that will be able to read Shakespeare, grease a car, play office politics, tell a joke, have a fight. At that point the machine will begin to educate itself with fantastic speed. In a few months it will be at genius level and a few months after that its powers will be incalculable." Despite the delay the plan had already in 1984, Roger Schank, who was usually more moderate and restrained than Minsky, asserted that one day there will be an omniscient machine, and that work was being done to this end. Statements such as these were probably what led David Gelernter to claim that the field of computer science is full of oddballs avid for novelty.

The programme certainly failed, but this did not lead to abandoning the underlying intentions, as Kurzweil's appearance on the scene shows. In May 2009 Kurzweil presented two documentaries about his ideas in Brookline, Massachusetts.[13] Karim Gherab was there, and he told me Kurzweil could only answer with vagueness when asked how he thought he might copy a mind (or a brain, if he felt this would be easier) on a computer[14].

In the book that was published containing a debate between Kurzweil and some of his critics, the only philosopher present was Searle (2002:71-72), who reiterates his well-known views on the matter, namely, the irreducibility of semantics to syntax and his "Chinese room" experiment (which, in my humble opinion, is a restatement of Leibniz' famous *mill* argument[15]), and he throws at Kurzweil three decisive objections. Searle finds fault firstly with Kurzweil's trying to give the public the impression that he understands what he actually doesn't understand, an ugly habit no doubt, and secondly with his taking as definitively established truths

[12] The corresponding citations are in González Quirós (1998), pp. 110 and 111.

[13] *Singularity Is Near* and *Transcendent Man*, presented at The Coolidge Corner Theatre on 11th May 2009 (https://www.kurzweilai.net/kurzweil-to-present-sneak-previews-of-excerpts-of-singularity-is-near-and-transcendent-man-films-at-coolidge-corner-theatre-may-11).

[14] He also resorted profusely to the peculiar and invalid argument that since techno-sceptics had been wrong many times, now he would be right.

[15] Monadology, 14.

theories that are not so; and lastly, Searle contends that we lack minimally clear knowledge of how the brain does what it does.

Michael Denton, a biochemist that leans toward the notion of "intelligent design", criticises Kurzweil for overlooking some essential characteristics of living beings that in no way seem to exist in the domain of machines. The first of these differences is the ability to self-replicate that living beings have at many different levels. This is a property that computers obviously lack, albeit some theoreticians, futurists as they are, have maintained that it will be possible to equip them with functions similar to this property life has, which is one that seems to establish a decisive difference.

Another property cited by Denton is the ability of living beings to grow and transform themselves, changing their shape and structure. All of this can certainly be called *information*, but we are very far from understanding and from truly knowing how to do what a simple hen does warming an egg: to unfold the information contained in the yolk so that a chick is developed. (This example is mine, not Denton's.)

Denton turns to Kant and his *Critique of Judgment* [16] to remind us of the peculiar entanglement of causes and effects that is typical of lifeforms, which does not seem reducible to an orthodox causal analysis from the point of view of science. The organic form is not susceptible to simple reduction. Denton (2002, 94) claims, for instance, that "no artifact has ever been built, even one consisting of only 100 components (the same number of components in a simple protein), which exhibits a reciprocal self-formative relationship between the parts. This unique property […] is the hallmark of organic design".

The readiness to jump over life, as if life were something simple, is markedly characteristic of the curious audacity of the functionalists and thinkers of Kurzweil's ilk. Life isn't easy to understand, if we mean understanding as we do in the sphere of mechanics. It would be foolish to deny that in the future things may be understood which we do not understand at all today, but it is no less arrogant to assume that we can disregard life if we want to comprehend something like consciousness. Furthermore, life is a phenomenon that is strictly tied to time, it is temporary in nature and it has certain, let's say, *negentropic* qualities, to use the term introduced by Schrödinger, which should not be overlooked. Nothing is gained by assuming that all complexity can be understood from the same simple elements we already know, completely, it would seem. It is no dishonour to admit there are things that are, for now, beyond us. The heart of the mistake that we make when we disregard the qualities of life that seem to be irreducible to mechanics and computing is to confound the abstract with the concrete. Smullyan, who believes the identification of the abstract with the concrete is one of the most tragic philosophical errors of our time, has said that the mind is as concrete as an entity can be (Smullyan, 1984). The fact is that, up to now, and setting aside computational or literary fantasies, the only judicious assumption we can make is that minds can be found in living beings. Life is a very difficult phenomenon to understand. It is supposed to fall under the purview of biology, but, as Emilio Cervantes[17] puts it, life slips like water through the basket of science. It would be pertinent, at this point, to recall Leibnitz' caution [18] on the difference between the works of God and those of man, but let us move on. The mind, for its part, is temporal and intuitive, utterly singular and elusive; one almost feels the temptation to say it is the only thing we know concretely, something surely very different to what the most complex and creative of programmes could be like.

3. Science and the properties of minds

From an epistemic point of view, it may be said that the main advantage of primary dualism over any form of reductionism is that the empirical

[16] Let us recall that Kant maintained there would never be a "Newton [...] of a blade of grass" (Kritik der Urteilskraft, § 75).

[17] This is the motto of his interesting blog: http://weblogs.madrimasd.org/biologia_pensamiento/

[18] "For a machine made by human artifice is not a machine in each of its parts. For example, the tooth of a brass wheel has parts or pieces which to us are no longer artificial things, and no longer have something recognizably machine-like about them, reflecting the use for which the wheel is intended. But the machines of nature, namely living organisms, are still machines even in their smallest parts, *ad infinitum*. It is this that constitutes the difference between nature and artifice, that is, between divine artifice and ours." (*Monadology*, 64, translation by Nicholas Rescher).

problem of the relationship between the brain and consciousness makes perfect sense for the dualist, whereas it is virtually nonsense for the reductionist positions. Those who believe there exists something different from the brain the neurophysiologists see, [19] a mind that is distinguishable from the physical body, the brain, in this case, know very well that there is something beyond their mere belief or the coherence and appeal of their ideas; they know very well that all of it is generated in a fiendishly complex system of associations and influences between conscious and temporal perception and the completely physical events that occur in the brain. Schrödinger (1992:93) made this point masterfully: "The world is a construct of our sensations, perceptions, memories. It is convenient to regard it as existing objectively on its own. But it certainly does not become manifest by its mere existence. Its becoming manifest is conditional on very special goings-on in very special parts of the world, namely on certain events that happen in a brain. That is an inordinately peculiar kind of implication, which prompts the question: What particular properties distinguish these brain processes and enable them to produce the manifestation?"

In addition to pointing out the metaphysical paradoxes of the case, Schrödinger outlines here an entire work programme which, in one way or another, is being carried out. This extraordinarily complex universe of associations is a matter for science, not philosophy, to explore, but it is not an impossible task, or one that does not make sense, however difficult it may seem today in our eyes.

Our current knowledge is that the human brain has an average of 86 billion neurons, and a "typical" neuron is connected through synapses to 1,000 to 10,000 other neurons.[20] The brain can establish or interrupt roughly a million connections per second, and it can keep usable information for decades, *labelling* it, using its meaning in manifold relations, changing its *location* or modifying it when necessary, and while doing all of this it coordinates the work of hundreds of muscles and the processes necessary for the body to function, without making us aware of it. The brain can interpret thousands of signals correctly and make appropriate decisions in milliseconds. In addition, it allows us to think, speak, maintain relationships and learn. All this activity is being studied with technologies of increasing subtleness, and we are acquiring immense amounts of information that must be combined, evaluated, interpreted and put into a coherent theory. Today we know relatively well which parts of the brain are involved in perception, how the brain works, how it processes the signals it receives, how it forms memories and how it controls muscle movements. We know which regions are activated with speech, when we look at something or when we do simple calculations, and we are beginning to know what happens when we make decisions.

It would be unusual if the task on the scientists' hands were not to become complicated by categorial concerns. The fact is that advances in such questions are much slower and limited in significance than would be desirable. We have celebrated years, decades and, almost, centuries of the brain; no one doubts the importance of these matters, and yet there are no palpable signs of any change of paradigm, except in areas where prophecy prevails over science.

Some may be tempted to believe that this is a field in which, as a revived Kant might say, it is not possible to make progress along the sure path of science. This is not what I think, if I am allowed the immodesty of expressing my opinion. I prefer to believe that we may be at the gates of some truly spectacular advances, rather than to assume we will come to the end of science. This notwithstanding, I do not believe that the kind of progress we can expect will be capable of solving any metaphysical enigma, for reasons very similar to those that make me doubt we will be able to remove the veil of Maya or to travel beyond space and time.

¿What can we expect? As the true *empiricist* I would like to be, what I anticipate is that a more precise science than the present one, but not necessarily very different, will allow us to

[19] The brain of which Bertrand Russell (1995:186) said, "I have been taken to task for saying that what a physiologist sees when he examines another man's brain is in his own brain, and not in the other man's".

[20] From Eric Chudler's web page at University of Washington: "Brain Facts and Figures" (https://faculty.washington.edu/chudler/facts.html; accessed on 12th January 2021).

understand better how the brain works, and consequently open the possibility of contributing purposely to the efforts to enhance the intellectual abilities within our grasp. This will make it possible, for example, to create new instruments to develop our capacities for perception, and even our intelligence. In other words, I believe that the brain will have *exoinstruments* connected to it in a rather simple and effective manner, to enhance its performance. I expect some sort of intellectual orthopaedics, of hybrid intelligence, will be possible, and that this will open new paths. I presume, furthermore, that this new form of hybrid intelligence will not come solely from the side of hardware, but also from software, based on the foreseeable improvement of the system of signs we use to think and to calculate, and of the ways to automate their relationships through new networks that are external to us or, in some sense, also hybrid. All of this might seem like science fiction, but perhaps we are not so far away from it.

Science is beginning to break free from conceptual frameworks and images that were, in a way, constraining it, and to equip itself with methods that will allow small but solid and steady advances[21]. To explain better what I mean I will make use of an analogy, referring to biochemist Michael J. Behe's commentary on Darwinism, as I believe it is an appropriate metaphor for what I am trying to say. Behe's criticism of Darwin, or, more properly, of contemporary Darwinism, moves along various fronts and, naturally, it does not deny biological evolution across different aspects of the very broad phenomenon of life. What he calls into question severely is its explanatory value. For Behe, from the moment in which it was possible to open the *black box* of molecular biology, the kind of explanations at the organism level that are typical of Darwinian arguments lack all power. Since any sufficiently expressive quote demonstrating how Behe's makes his argument would be too long, I copy in a footnote[22] one of

[21] Terrence Sejnowski, a computational neurobiologist at *Salk Institute*, recognises this: "The way that neuroscientists perform experiments is biased by their theoretical views", https://stage.edge.org/response-detail/10881.

[22] To Darwin, vision was a black box, but after the cumulative hard work of many biochemists, we are now approaching answers to the questions of sight. The following five paragraphs give a biochemical sketch of the eye's operation. […] Don't be put off by the strange names of the components. They're just labels, no more esoteric than *carburetor* or *differential* are to someone reading a car manual for the first time. […]

When light first strikes the retina a photon interacts with a molecule called 11-*cis*-retinal, which rearranges within picoseconds to *trans*-retinal. (A picosecond is about the time it takes light to travel the breadth of a single human hair.) The change in the shape of the retinal molecule forces a change in the shape of the protein, rhodopsin, to which the retinal is tightly bound. The protein's metamorphosis alters its behaviour. Now called metarhodopsin II, the protein sticks to another protein, called transducin. Before bumping into metarhodopsin II, transducin had tightly bound a small molecule called GDP. But when transducin interacts with metarhodopsin II, th GDP falls off, and a molecule called GTP binds to transducin. (GTP is closely related to, but critically different from, GDP.) […]

The above explanation is just a sketchy overview of the biochemistry of vision. Ultimately, though, *this* is the level of explanation for which biological science must aim. In order to truly understand a function, one must understand in detail every relevant step in the process. The relevant steps in biological processes occur ultimately at the molecular level, so a satisfactory explanation of a biological phenomenon – such as sight, digestion or immunity – must include its molecular explanation.

Now that the black box of vision has been opened, it is no longer enough for an evolutionary explanation of that power to consider only the *anatomical* structures of whole eyes, as Darwin did in the nineteenth century (and as popularizers of evolution continue to do today). Each of the anatomical steps and structures that Darwin thought were so simple actually involves staggeringly complicated biochemical processes that cannot be papered over with rhetoric. Darwin's metaphorical hops from butte to butte are now revealed in many cases to be huge leaps between carefully tailored machines – distances that would require a helicopter to cross in one trip.

Thus biochemistry offers a Lilliputian challenge to Darwin. Anatomy is, quite simply, irrelevant to the question of whether evolution could take place on the molecular level. So is the fossil record. It no longer matters whether there are huge gaps in the fossil record or whether the record is as continuous as that of U.S. presidents. And if there are gaps, it does not matter whether they can be explained plausibly. The fossil record has nothing to tell us about whether the interactions of 11-*cis*-retinal with rhodopsin, transducin, and phosphodiesterase could have developed step-by-step. Neither do the patterns of biogeography matter, nor those of population biology, nor the traditional explanations of evolutionary theory for rudimentary organs or species abundance. This is not to say that random mutation is a myth, or that Darwinism fails to explain anything (it explains microevolution very nicely), or that large-scale phenomena like population genetics don't matter. They do. Until recently, however, evolutionary biologists could be unconcerned with the molecular details of life because so little was known about them. Now the black box of the cell has been opened, and the infinitesimal world that stands revealed must be explained.

his texts (1996: 18ff.) on the biochemistry of vision, which shows how far our understanding of this function has reached beyond the organ-level of analysis. Darwin, in any case, could not have reasoned any other way, as the discipline of biochemistry did not yet exist in the second half of the nineteenth century.

Post-Cartesian materialists have been materialists not because they know what the brain does, but in spite of not having the faintest idea of what it does and how. They have been *a priori* materialists, believers in the curious metaphysical idea, if I may put it this way, that one is more credible than two[23]; that it was reasonable that in the universe there should be a single substance, and that the supposition that there might be two is scandalous. In other words, for classical materialism the brain could have well been made of solid wood. This materialism emanated from something entirely independent of the peculiar biological nature of the brain. Here Behe's critique of Darwinism becomes meaningful. We do not yet have all the keys to understand how the brain works, but we have more every day, and it would be regrettable that exceptional research should be interrupted or squandered in the name of a metaphysics that would make us think we already know what mental states are, namely, the products of the theoretical brain, let's say, of a wooden brain.

I am perfectly aware that the analogy I have just drawn has, as all analogies do, serious flaws, and that materialism is slightly subtler than the assertion that the brain could well be a piece of wood. Nevertheless, the *black box* theories of the brain certainly have led to the absolutely unjustified rise in prominence of the computational notion of mind, which, as we have discussed, was developed on the foundation of the behaviourist and functionalist criticisms of cartesian dualism –which, incidentally, was utterly misunderstood–, acting, as it were, in a manner befitting the old Spanish proverb, *a moro muerto*, *gran lanzada*.[24]

[23] This is one of the objections that Sherington (1984) makes to materialism in the first half of the twentieth century.

[24] Literally, "*valiant lancing of a dead Moor*," meaning it is easy to claim a great victory over a foe that is already dead (as Falstaff would agree).

Finally, we cannot continue confusing the logical analysis of the products of the mind, or perhaps we may say the brain, with the true knowledge of what the structures of the brain are that make possible our conscious activity, and how these structures operate.

The confusion of the mind with a computational system has lasted for too long, so it is worthwhile to try to understand the reasons that have allowed such a woolly hypothesis to remain on its feet. I believe one of them is the fact, as forgotten as decisive, that, as Schrödinger liked to say, the mind can only be *experienced* in the singular, which allows us to speak in the fullest sense of the problem of *other minds*. Hence, this absolute singularness and indistinctiveness of minds can be accommodated easily in the computational model, for which the mind is a single abstract entity. I think there is a further reason that explains the confusion, if indeed it is a confusion, between mind and brain from this perspective. I am referring to the fact that the extraordinary technological advancements of the digital age have brought about a synthesis of reductionist technologies (or technologies inspired in knowledge that is reductionist methodologically) and the actual digital technologies, which are not reductionist or physicalist, but rather, they rely on the capacity to handle semantic properties, and that this synthesis has contributed to the confusion of the metaphysical meaning of the former and the latter. It is necessary, however, to distinguish both sources of technology. Doing so may help to dispel the illusion on which the computational model of the mind rests. Reductionism as an explanatory strategy seeks to determine the elements that make up a given reality and connect them to elucidate the phenomena that characterize it. On the other hand, the creation of any digital entity is a process in which signs or units are extracted from a meaning that is given previously; a meaning that is not deciphered but, *au contraire*, encoded digitally. That such encoding lends itself wonderfully to lightning-fast electronic treatment should not confuse us regarding this essential difference.

Entirely aside from any computational metaphor, the science of the brain is in a position to obtain ever more precise knowledge of how neurological biology works, and we can expect this will lead to technology-based improvements of our intellectual performance, which without much hesitation we might call hybrid intelligence. I have no doubt these advances will, when the time comes, require we refine the theoretical paradigm that can accommodate all these new forms of knowledge, but I believe the most appropriate metaphysics will continue to be, in one way or another, *dualist*, and I would wager that no empirical discovery will ever knock down a well-established metaphysical category, such as the *mental* category is.

To conclude this analysis, I believe categories of this kind are sufficiently protected from any reductionist threat for various reasons of principle, such as those that link consciousness with perception of time, an aspect of reality that is not so fully at our disposal as space; or those that have to do with the peculiar freedom our understanding must enjoy, if we are to profess having the capacity to produce forms of knowledge that are not absurdly contradictory. Regarding this last consideration, one of its best and briefest articulations is Epicurus' caution – which in my view is as brilliant as the Euclidean proof that there are infinite prime numbers – that "He who asserts that everything happens by necessity can hardly find fault with one who denies that everything happens by necessity; by his own theory this very argument is voiced by necessity." [25]

I therefore completely agree with a recent text by Juan Arana (2009:302-303): "Since a light cough can interrupt my freedom and my very self-awareness, what problem is there in admitting that exercising it is linked to the coordinated or unaligned activity of some set or other of neurons, or to the emission and reception of this or that neurotransmitter? It will be providential when such mysteries are solved, if indeed their unveiling proves to be a benefit to humankind. However, and since what is sought on the horizon of the neurosciences is to establish a correlation between neuronal activity and the awakening of consciousness or the exercise of the will, the possible discovery of such correlations, even if it is complete, would in no way equate to a total naturalization of consciousness and freedom. The only thing that would be discredited with such advances is a stark dualism of a kind that Descartes himself never defended. The unity of man implies that the dimensions body and soul we find in him are so intimately intertwined that we wouldn't know how to separate them fully, neither physically nor conceptually. Traditionally, it is assumed without any trouble that this affects our notions of soul, psyche or spirit, but the truth is it affects bodily or material notions in the same way. In other words, it makes as little sense to speak of mere neurons, molecules and atoms as it does to speak of mere consciousness, will or freedom. In both cases these are abstractions, aspects of reality that are more or less defined, which we have separated conceptually, artificially cutting their links with the whole of which they are a part, and assuming that we can use them as a first approximation to the truth we are searching for."[26]

4. Hybrid intelligence and the new collective mind

When attempts have been made to imitate how the brain works by building neural networks, the mistake has been to assume that a real brain uses the same kind of relatively basic physical and logical architecture as that of ordinary software. Research into the properties of synapses and how they work, however, suggests they are considerably more complex. The efforts of mathematicians, neurobiologists and many other specialists are beginning to show that the circuitry of the brain relies on compositional and physical properties which, possibly without the need to resort to quantum mechanics, will allow us to improve our knowledge of how the brain works, and at the same time inspire ways to build faster and more powerful computing architectures.

As regards possible advances in the knowledge of the *physics* of the brain that supports our mental activities, we will relate the story of the memristor, following the suggestions made in a paper by Justin Mullins (2009). In 1971, Leon Chua[27], a young electronic engineer in California,

[25] Epicurus, Aphorism 40 of the Gnomologium Vaticanum.

[26] Excerpt translated for this paper from the original in Spanish.

[27] Chua's very technical text can be found here: https://ethw.org/w/images/b/bd/Memristor_chua_article.pdf.

had the impression that the state of the theory concerning the nature of electronic circuits was mathematically deficient. In the same way as Mendeleev was able to suggest there were gaps to be filled in his table of chemical elements, Chua thought that in addition to the three known elements (or devices) in a circuit – the capacitor, the resistance and the inductor – there must be a fourth. The reasons for his belief were strictly mathematical in nature, namely, that between four entities (in circuit theory they are: the electric charge; its behaviour in time, that is, the current; the magnetic flux; and the voltage) that hold binary relationships with each other directly, there must be six basic ways in which they are related to each other. However, circuit theory posited only five,[28] which to Chua was a displeasing flaw. There was a missing relationship between the electric charge and the magnetic flux. This sixth relationship should do something that could not be achieved through combinations of the others. Specifically, Chua thought that it should behave like a resistor which changes its resistance when charge flows through it, and in addition *remembers* the amount of charge that has flowed through it by keeping its last resistance value when the current is turned off. Chua called his device a memristor (*memory resistor*). For almost forty years the memristor was a strictly theoretical creature, because no physical device existed capable of performing that precise function.[29] At the dawn of the new century, there began to emerge materials and designs that could do so. These were systems that worked at the nanotechnological scale, unobservable at the scale of the millimetre.[30] The discovery promised to be useful to build flash or solid-state memories, which deliver much faster writing and re-writing speeds. But, more germane to our purposes, the real novelty came when the truly surprising behaviour of a unicellular creature, the *Physarum polycephalum*, was described. It appears this slime mould could solve certain basic puzzles and, more importantly, it seemed capable of anticipating events that occurred periodically, which led researchers to conclude that, despite it not having neurons, it must have some kind of memory. Max di Ventra, a San Diego physicist who knew of Chua's ideas, learned of the case and compared it to the behaviour of a memristor, and later, in collaboration with Yuriy Pershin (2008) and others, created a model of a memristor which, it seems, behaves as a synapse does.

We have mentioned this example because in our view it shows one of the many ways in which it will be possible gradually to advance our knowledge of the singular physics of the brain. We believe the key will be in that our technologies learn to do what living cells, what neurons, do, and more specifically how synapses work, for instance, without supposing, on the other hand, that our information processing machines can provide any insight. To the extent that this may be feasible – and the challenge is almost of extravagant difficulty – perhaps it would be possible to think of a convergence of minds and machines, which today is very distant from our immediate agenda. The nature of the superiority of life over formal design is such that it clearly refutes Kurzweil's (2005:478) supposition that "The patterns are more important than the materials that embody them." We do not mean to deny the need for a general theory of the functioning of the brain, for something which we may call a *model*, but we do maintain, firstly, that the groundwork of knowledge laid so far is still glaringly insufficient to propose such a theory, and secondly, that the models inspired in the formal analysis of knowledge, the purely logical and/or functional models, are based on an error of principle. One of the latest things in neurobiology has been to assume that the brain works in a Bayesian manner, through anticipation mechanisms, drawing particularly from Friston's research (Huang, 2008) and from popular science works like Hawkins' (2004).[31] But even supposing that this theory is fruitful, the most interesting knowledge will always be that of the properties

[28] Charge with current and magnetic flux with voltage give us two of those possible relationships. The other three, to make the total of five, are those that describe the three elements or devices considered traditionally in circuit theory, namely, resistor, capacitor and inductor.

[29] Indeed, the validity of the memristor even as a theoretical circuit element has been challenged. (See Abraham (2018).)

[30] See Strukov et al. (2008).

[31] A review of his book, as well as helpful information to follow Hawkins' ideas, can be found in http://www.uoc.edu/uocpapers/3/dt/esp/climent.pdf

of neurons, and the systems they form, which make possible the Bayesian behaviour.

We do not think the as yet remote possibility that by these, let's say, empirical routes we may develop technologies that complement and/or enhance our mental functions should entail a conceptual revolution, although we have no difficulty in admitting that some of the countless revolutions suggested by historians have been based on much less. After all, some may come to recognise that, as Nicholas Humphrey[32] puts it, "the 'Cartesian theatre of consciousness', about which modern philosophers are generally so sceptical, is in fact a biological reality", that our brains are the way they are for the very purpose of staging this mental theatre. Even from a very neutral perspective, or a purely pragmatist one, we should be interested, not so much in solving a problem that is metaphysical in nature, but in expanding our knowledge of mind and brain, so that we can enhance our performance and develop supports to handle many difficulties and problems.

A thinker as scantly mythomaniac as Freeman Dyson[33] has spoken, for instance, about the possibility of implementing some form of radiotelepathy, a direct communication of feelings and thoughts between different brains. This is not too different from that what we do when we speak over the phone, for example. To make radiotelepathy possible, according to Dyson, we would need to know how to convert neural signals into radio signals, build microscopic radio receptors, and also be able to read the mental meaning of neural signals, which is something Dyson does not mention. This is knowledge we do not possess, but it is not inconceivable to attain it. Dyson also speculates with the possibility of feeling what a bird feels when flying, or what a deer feels when shot, a proposition we imagine may seem as fanciful to Thomas Nagel as it does to us.

There is a second sense in which we can speak of hybrid intelligence, if we consider the changes that will take place eventually, as a result of the quest for what we might call the "new collective mind", that is, integrating into our working intelligence the new information and knowledge resources afforded by the growth of the Internet, by its specialization and by each person's capacity to combine it all into a coherent image of reality.

It seems clear that two sources of innovation can be deemed to have great power to modify our intellectual habits, and therefore the functions and dimensions of our operative intelligence of things, namely, digitalisation and the functioning of the network we know as the Internet. The first novelty lies in the fact that the information available has gone from being recorded on physical mediums, from being written in material documents, to being recorded digitally, in documents that are intangible but very easy to handle. This makes possible spectacular improvements in accessibility, transparency, economy and participation. A second big innovation is that reading can cease to be a purely passive activity, in that readers are able to leave a mark on what they read. This will increase greatly the amount of information available, although it also entails certain obvious risks. Thirdly, it will be possible to write under very different conditions to those of the past, with barely any scarcity of documentary support and with the prospect of obtaining responses to what is written almost immediately. Consequently, conditions will be absolutely ideal for debates, conversations and correspondence between scholars, which are the means by which modern science began to rise.[34] Lastly, the spectacular rise in the number of people who can participate in any debate makes it reasonable to consider, as Tim O'Reilly suggests, that ideas are becoming in themselves a particularly relevant form of social software. We should not forget that the biggest business on the Internet, Google, is based precisely on exploiting very smartly what people do when they use the Internet. It is a tool that exploits *social software* as a primary source.

We should bear in mind that, sooner rather than later, we will have the ability to handle with some ease massive collections of data relevant to any particular purpose, and that those collections will be constantly renewed since, to put it this way, accompanying the observed facts we will always be able to find the best reasons that have

[32] https://www.edge.org/response-detail/10428.
[33] https://www.edge.org/response-detail/10313

[34] See González Quiros (2009 a) and González Quirós & Gherab Martín (2009 b).

been discerned to support their validity. This will mean that everything will be continually re-edited, in a manner of never-ending and instant story that some may see as a terrible threat, if they are slaves to the idea that the most solid truths ought to be written in some inaccessible place, in bronze letters. Those of us who believe truth is in propositions and that these are, above all, immaterial, as immaterial as our consciousness, have reason to celebrate, because we will have at our disposal something which we may almost be tempted to compare to an inexhaustible source of wisdom – at least, that is, for those judicious drinkers who may delight in it.

The decisive influence writing or the printing press have had on human progress is a commonplace of cultural history which everybody accepts, and it is also very clear that the digital era is creating possibilities that are considerably more powerful and effective than the ones ushered in by those historical technologies. Nevertheless, it is immediately evident to anyone faintly familiar with the use of the Internet that social, cultural and institutional burdens are very seriously hindering genuine technological possibilities. After all, Bacon was right, and, since information is power, mere technological power is not enough to attain real power. But that is, of course, another question.

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PUBLIC POLICIES IN THE FIELD OF ADVANCED MATERIALS

International Tendencies and Subsidies to the National Policy for Advanced Materials in Brazil

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KEY WORDS

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ABSTRACT

Currently, advanced materials are a source of interest for the private sector, since they are regarded as the foundation for the promotion of technology-based innovation and, also, because they have the potential to add value and competitive differential. Considering the efforts of the Brazilian Ministry of Science, Technology, Innovations, and Communications (MCTIC), which has established advanced materials as a priority, this work presents an analysis of the most important international public policies in the field of advanced materials, thus identifying their main characteristics, tendencies, and priorities, with the intent of subsidizing the devising of a National Plan for Advanced Materials in Brazil.

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GLOBAL KNOWLEDGE ACADEMICS

1. Introduction

In Brazil, the promotion and incentive applied to the development of science, technology, and innovation are pivotal premises contemplated in article no. 218 of the Federal Constitution of Brazil. In this context, advanced materials can be considered one of the main enabling areas with great innovative potential. This area's development is historically associated with the evolution of mankind, deriving from it the names of historical periods, such as the stone and metal age, with breakthroughs, particularly in agriculture and war, for the population that dominated the transformation of these materials.

Today, advanced materials continue to arouse the interest of the academic world and the private sector. They are considered the basis for the promotion of technology-based innovation, due to the potential for adding value and competitive differential. Taking into account the efforts of the Ministry of Science, Technology, Innovation, and Communications (MCTIC) for the national scientific development, and the validity of the National Strategy for Science, Technology, and Innovation (ENCTI 2016-2022) (MCTIC, 2017), which establishes as a priority the Convergent and Enabling Technologies, which includes advanced materials.

Taking this context into account, a research project was developed at the National School of Public Administration (ENAP), in the scope of the program "Specialization in Management of Science, Technology and Innovation Policies" (ENAP, 2020), adding elements of training and professionalization of management in the area of S, T&I, and stimulating the search for key elements, national and international trends, and priorities in the field of Advanced Materials to subsidize a Brazilian Public Policy for Advanced Materials.

This work presents an analysis of public policies and prospective studies in the area of advanced materials, to identify the main characteristics or structuring axes of such policies; identify trends in the area of advanced materials and present subsidies, in particular themes and priority actions for the development of a National Program of Advanced Materials. The countries/blocks selected for analysis were the European Union, BRICS, United States, Japan, and Germany, due to the increased investment in R&D and the relevance of the area of Advanced Materials as a technology capable of driving innovation and economic development.

2. Methodology

For the development of this study, an analysis of public policies and prospective studies in the area of advanced materials were carried out to identify the main characteristics or structuring axes of these policies; identify trends in the area of advanced materials and present subsidies, in particular themes and priority actions for the development of a National Program of Advanced Materials. The countries/blocks selected for analysis were the European Union, BRICS, United States, Japan, and Germany, due to the increased investment in R&D and the relevance of the area of Advanced Materials as a technology capable of driving innovation and economic development.

3. Strategic Relevance of the Area

Considering its transversal reach, the area of advanced materials is historically associated with the fields of chemistry and physics of materials, materials engineering, and others. The importance of this area for the economy and technological development is unanimous, as it has improved the performance of materials, reduced costs, increased component life, and provided more sustainable disposal at the end of the product cycle, among other advances.

3.1. Advanced Materials Concept

Corroborating the ENCTI 2016-2022, "Advanced Materials" are "materials and their associated technological process, with the potential to be exploited in high added-value products and applications". It is a multidisciplinary theme (for instance, involving the fields of physics, chemistry, and applied mathematics), transversal (encompassing technological areas such as electronics, photonics, and biosciences), and with a multi-sectoral market (covering the energy, transportation, health care, and packaging markets).

3.2. Innovative Potential of Advanced Materials

It is important to note that advanced materials (new materials, functional materials, synthetic materials, and the like) are some of the most direct forms of adding value to already established technologies. The use of these materials, or the improvement of processes to obtain traditional materials, manage to reduce costs, improve physical and chemical properties (for example greater resistance to thermal degradation, abrasion, and aging, reduction in density, increase in electrical conductivity, among others), add new functionalities (multifunctional materials), generate more environmentally sustainable processes, provide new purposes to waste and several other direct applications (CGEE, 2010).

3.3. Economic Potential of Advanced Materials

The business and industrial sectors focus on the development and use of Advanced Materials to put better products on the market, keeping the investment/return ratio as favorable as possible. Private investment in new technologies, including advanced materials, has as its main objective the creation and maintenance of competitive advantages, including: (i) reduced costs and increased profitability; (ii) sustainability and environmental impact; (iii) increased customer satisfaction and loyalty; (iv) regulatory compliance; (v) competitiveness and market differential; among others.

3.4. Academic Importance of the Theme

The area of Advanced Materials is mainly conducted by professionals with training in material sciences, engineering, mathematics, physics, and chemistry. Currently, Brazil, in the area of materials and related fields, offers 66 graduate courses recognized by the Ministry of Education (MEC) (MEC, 2020) and 36 postgraduate courses in the area of materials (Master's and Ph.D.), recognized and evaluated by the Coordination for the Improvement of Higher Education Personnel (CAPES) (CAPES, 2020). On average, there are about 7000 graduate and 500 postgraduate vacancies. From a global perspective, there is a significant increase in scientific research in the area of Advanced Materials, which is reflected in a growth of approximately 140% in scientific production between 2004 and 2014 (BLAND, 2014). In Brazil, there is already a relatively established community, responsible for the production of more than 5000 articles/documents indexed in the triennium 2016-2018, according to the SJR Portal (PORTAL SJR, 2018). This production corresponds to approximately 2.5% of world production in the area. This puts the Brazilian community in a position of relative prominence in the world context.

3.5. Materials Research Groups

Regarding the Brazilian groups dedicated to research in "Materials", 530 research groups were found in the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq) (PORTAL CNPq, 2020), which presented the term "Materials" next to the group name. Considering a universe of 37.640 research groups in the 2019 directory, the 530 research groups associated with the materials represented 1.4% and approximately 2,809 researchers, as the average of researchers per research group was 5.3 researchers.

4. Advanced Materials Programs in Brazil

Historically, the Brazilian government, particularly through the MCTIC and its development agencies, and the State Research Support Foundations (FAPs), has boosted structured programs for the development of the national S, T&I. Therefore, the four main newest national research, technological development, and innovation programs, which cover several areas, including Advanced Materials, are National Institutes for Science and Technology (INCT); Research, Innovation and Dissemination Centers (CEPID) of the São Paulo State Research Support Foundation (FAPESP); National System of Nanotechnology Laboratories (SisNANO); and the Brazilian Company of Research and

Industrial Innovation (Embrapii). Below is the main information about the programs.

INCT (INCT, 2020; CONFAP, 2016): The INCT Program was officially launched on November 27, 2008, by the MCTIC, via CNPq, with ambitious and comprehensive goals, associated with the possibility of mobilizing and articulating the best research groups in areas related to scientific breakthroughs and strategic areas for the country's sustainable development; boosting basic and fundamental scientific research in the international context, in a competitive way; stimulating the development of cutting-edge scientific and technological research, associated with applications to promote innovation and entrepreneurship, in a close effort with innovative companies. From the standpoint of support provided to INCTs, the MCTIC made three public calls, via CNPq, in 2008, 2010, and 2014, for R$ 1.1 billion, including resources from the MCTIC (FNDCT), CNPq and FINEP, CAPES and some State Foundations for Research Support, such as FAPESP, FAPERJ, and FAPEMIG. In Advanced Materials, based on the lines of research and technological development, among the 122 INCTs contracted in 2008, eight INCTs were identified (7% of the total INCTs, or 25% of the total INCTs in related areas) with actions that directly or indirectly involve the area of advanced materials.

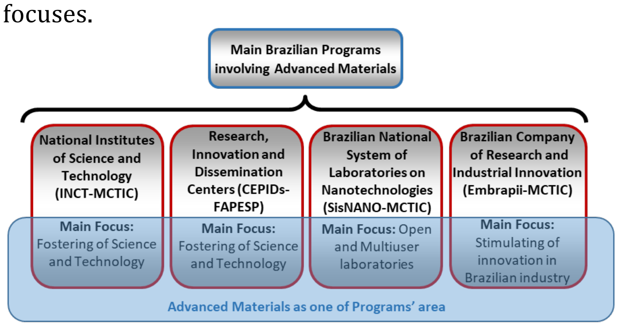
CEPID (CEPID, 2020): The CEPID program was conceived by the FAPESP in 2000, with the support of 11 research centers from 2001 to 2013. In 2011, a second call for proposals was announced, which originated the 17 CEPIDs currently supported. The program aims to develop basic or applied research, focused on specific themes; contribute to innovation through technology transfer; and provide extension activities focused on primary and secondary education, and also for the general public. The most relevant profile of the Centers is the multiplicity of their activities. The Centers are responsible for the development of fundamental or applied research at a high level, but also the search for technology-based innovation opportunities, entrepreneurship, knowledge transfer to the private sector and society. The total financing for the 17 Centers is estimated at about R$ 1.4 billion. R$ 760 million from the FAPESP and R$ 640 million in salaries paid by the host institutions to researchers and technicians over 11 years. Regarding the Advanced Materials subject, based on the lines of research and technological development, four CEPIDs were identified (24% of the total CEPIDs), with actions that directly and indirectly involve this area.

SISNANO (SISNANO, 2020): One of the key actions of the Brazilian Nanotechnology Initiative (IBN), the SisNANO was established by Ordinance No. 245 of April 5, 2012, which consists of a system of laboratories focused on research, development, and innovation (RD&I) in nanosciences and nanotechnology. The pivotal feature is the multi-user character and open access, through the presentation of project proposals in PD&I, or the request for services. The SisNANO is responsible for the General Coordination for Development and Innovation in Strategic Technologies (CGTE), the Secretariat of Entrepreneurship and Innovation (SEMPI), the Ministry of Science, Technology, Innovation and Communications (MCTIC). The first stage of the System (2013-2018) had two categories of laboratories: the Strategic (08 laboratories) directly associated with the Federal Government and the Associates (16 laboratories). Since the beginning of the Program in 2013, the laboratories have received approximately R$ 88 million in resources from the MCTIC/FNDCT. The main objective of these resources was to improve the laboratory infrastructure, the maintenance of the technical-scientific staff qualified to develop the missions of the laboratories, and enable open access to the laboratories, serving users and institutions in the public and private sectors.

EMBRAPII (EMBRAPII, 2020): Embrapii is one of the research institutes of the MCTIC, qualified by the federal government as a social organization. The mission is to support technological research institutions, in specific areas of skill, to carry out technological research development projects for innovation, in cooperation with companies in the industrial sector. The focus is on business demands and the target is risk-sharing in the pre-competitive phase of innovation. In the area of Advanced Materials, Embrapii currently has the following accredited-Embrapii Units: Technological Research Institute (IPT) in high-performance materials, SENAI Institute of innovation in metallurgy and special alloys, National Center for Research in Energy and Materials (CNPEM) in biomass processing, SENAI Institute of Innovation in Polymer Engineering and others.

Figure 1 is an organization chart that presents four of the main national programs dedicated to the development of science, technology, and innovation in Brazil, interfaced with the area of Advanced Materials.

Figure 1. Organization chart with the main Brazilian programs for Advanced Materials and their respective focuses.



Source: Own author, 2020.

5. International Programs for Advanced Materials

Advanced Materials are strategic and a priority for most societies whose economy is knowledge-defined. Below is an analysis of the key strategies adopted by the European Union, BRICS, the United States, Germany, and Japan in Advanced Materials.

5.1. European Union

Generally speaking, the theme of science and technology, with specific plans for the field of converging and enabling technologies, where advanced materials are included, remains a priority axis in European economic development. It is also its main instrument in the "Horizon 2020" framework program. It has three main strategic axes (Excellence Research, Industrial Leadership, and Social Challenges). In the Work Programmes (2014-2016, 2016-2018, and 2018-2020), the theme Advanced Materials has had a greater presence in the axes of Industrial Leadership and Excellence Research, associated with enabling technologies (Key Enabling Technologies – KETs). KETs, like advanced materials, photonics, nanotechnology, and biotechnology, are at the core of innovative products. For instance, smartphones, energy storage systems, lighter structures, nanomedicines, intelligent fabrics and others (Comissão Europeia, 2014, H2020 FET, 2017).

5.2. BRICS

BRICS, an acronym associated with the founding member countries – Brazil, Russia, India, and China – are a political group for cooperation in different sectors of society. The main actions of BRICS are focused on two strands: coordination in international meetings and organizations, and the construction of an agenda of multisectoral cooperation among members, particularly with regard to economic and scientific interests. In 2015, a Memorandum of Understanding for cooperation was signed, where three axes of governance and decision-making were established: meeting of Ministers of ST&I; the meeting of Senior Officers on ST&I; and Working Groups on ST&I. Regarding Advanced Materials, four actions involving this area were identified: BRICS Center for Materials Sciences and Nanotechnology; BRICS Working Group on Research Infrastructures and Mega Science Projects; BRICS Forum for Young Scientists; and BRICS Development Agencies – Joint Multilateral Call (BRAZIL BRICS, 2017).

5.3. United States

The U.S. innovation system strongly values investment in science, technology, and innovation, made primarily by the government through its mission-oriented agencies, but also with strong private sector influence. One of the most interesting points in the materials area in the United States is the attention to the interface between the materials area and advanced industry. The country has established several public policies to revitalize and increase the competitiveness of American industry. From the American standpoint, the area of advanced materials plays an important role in the advanced industry, since the goal is to achieve multi-functionality of materials, increasing the useful life of machinery, developing reference materials, reducing costs, and increasing physical performance. As such, the field of materials has been identified as one of the pillars of the National Plan for Advanced Industry, together with technological platforms for production, advanced industrial processes, and data and development infrastructure (Strategic Plan, 2012).

5.4. Germany

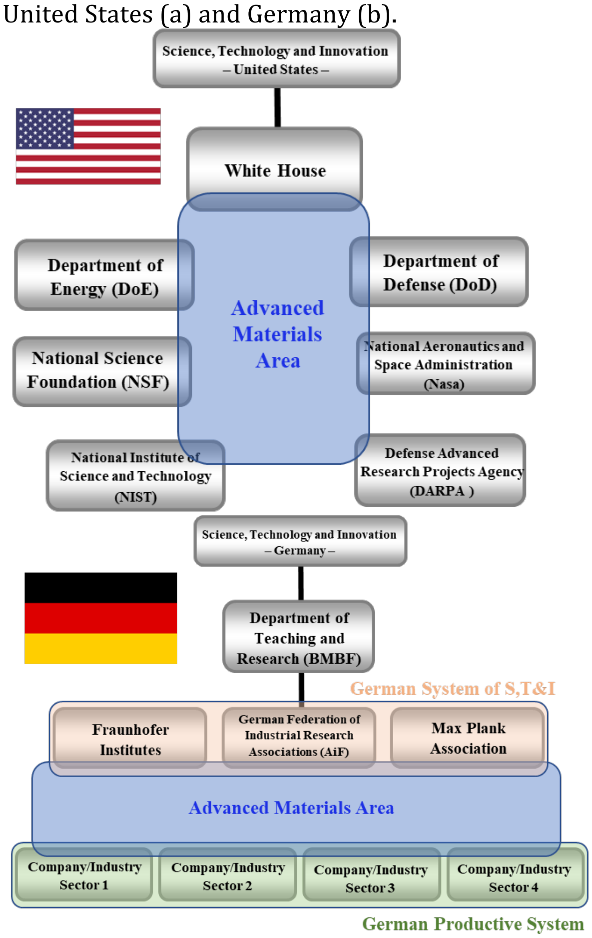
Science, technology, and innovation are the main pillars of the German economy, which restructured the country after the Second World War. They are characterized by multidisciplinary and high-tech infrastructures, with a social and entrepreneurial culture aligned with innovation. In advanced materials, the domain is mostly settled by the following institutions: Fraunhofer Association; German Federation of Industrial Research Associations; and Max Plank Association. From the point of view of strategic planning for the materials area, the German Federal Ministry of Education and Research launched its main materials innovation program in 2004, known as Materials Innovation for Industry and Society (WING). The central aim of the program is to increase innovation in the field of materials for industry through mission-oriented research, while, at the same time, leveraging the use of materials to overcome social, economic, and the "major German challenges" – mobility, infrastructure, health and the environment (Federal Ministry, 2019).

5.5. Japan

Japan is one of the world's great examples of how a country with a small geographical size, few natural resources, and great weather vulnerability can, through science, technology, and innovation, be one of the world's great economic and wealth-generating peaks. A major part of Japanese knowledge production in the field of materials is conducted by universities. There are three other institutions with an important role in Japanese technological development in materials: the National Institute of Advanced Science and Technology, the Japanese Agency of Science and Technology, and the National Institute of Materials Sciences. Japan's 5th Basic Science and Technology Plan (2016-2020), which is equivalent to our National Science and Technology Strategy, has chosen Nanotechnology and Advanced Materials as one of its four priority areas, along with the analysis of large sets of stored data (big data), biotechnology and artificial intelligence. As in Brazil, in Japan, the areas of nanotechnology and materials are considered to have a close epistemological relationship, with a special economic-technological dimension, when associated with manufacturing and information and communication technologies.

As an example, Figure 2 shows the organizational charts that represent the support system for the area of advanced materials in the United States (a) and Germany (b). The remaining organizational charts can be seen in (Bellucci, 2019).

Figure 2. Organization chart representing the support system to the field of advanced materials in the United States (a) and Germany (b).



Source: Adapted from Bellucci, 2019.

6. Main Characteristics and Trends Identified

Based on the main documents related to the topic of Advanced Materials, and on the history of promoting S,T&I in each country/group of countries, below is a summary of the main characteristics and trends of each analyzed international program.

European Union: (i) Strong international cooperation with the intent to promote scientific and technological development; (ii) Encouraging the internationalization of research projects and human resources training, with international teams, and strong exchange of researchers; (iii) No prioritization of classes or applications for advanced materials; and (iv) Encouraging the strengthening and involvement of micro and small technology-based companies.

BRICS: (i) Strong international cooperation to promote scientific and technological development and human resource training; (ii) nanomaterials, materials for energy, magnetic materials, and materials for biotechnology and health as priority areas; and (iii) fostering unique research infrastructures and their sharing.

United States: (i) Decentralization of the U.S. strategy for advanced materials through agencies, departments, and foundations of the U.S. strategy for advanced materials; (ii) taking into consideration the percentage invested by the country in S, T&I, the fields of defense, health, energy, nanomaterials, and advanced industry were regarded as a priority; (iii) the identification of materials as one of the pillars of the national industry's rehaul, and (vi) the implementation of a national action to use computational tools to accelerate the materials' development.

Germany: (i) Excellence of national institutions associated with the scientific and technological development of advanced materials; (ii) industrial orientation mostly geared towards the development of industry and attention to small and medium-sized technology-based enterprises; and (iii) emphasis on the development of new materials using simulation and modeling computational tools.

Japan: (i) research and development activities of advanced materials conducted mainly by public research institutions, especially universities; (ii) public research oriented towards the demands and needs of the productive sector; (iii) fields of convergent technologies as priorities, especially the convergence between nanotechnology, advanced materials, and advanced manufacturing; (iv) a high degree of strategic coordination by federal agencies, associated with routine international prospecting activities; and (v) emphasis on the development of new materials using computational tools for simulation and modeling.

Table 1 lists the main characteristics and trends identified in public international science, technology, and innovation programs and documents in the area of advanced materials from the countries studied.

Table 1.
List of main characteristics and trends identified in international public S, T&I programs, and documents in the field of advanced materials.

Country/Group of countries	International Cooperation	Training of Human Resources	Supporting the Private Sector	Financing fo the S&T	Priority Areas	Other features
European Union	- Strong international cooperation for the development of S&T in the EU.	- Encouraging the training of specialized human resources.	- Stimulating micro and small technology-based companies.	- Support for major European projects.	- Not prioritizing classes or applications for advanced materials.	- Promotion of pilot plants for tests and scaling up.
BRICS	- Strong international cooperation to promote S&T.	-	-	- Strong incentive to joint S&T Multilateral Calls, including for Advanced Materials	- Nanomaterials, materials for energy, materials for biotechnology, and health.	- Promotion of singular research infrastructure s.
United States	-	-	- Materials as a pillar for the revitalization of the national industry.	- Promotion of R&D in advanced materials, via national agencies (NASA and DOE).	- Defense, health, energy, nanomaterials, and advanced industry.	- Effort to join materials and computationa l tools to accelerate R&D.
Germany	-	-	- Materials developed according to industrial needs.	- Investment in oriented by a mission and looking for excellence in research.	-	- Strong use of computationa l tools for R&D.
Japan	-	-	- R&D activities driven by demands from the private and industrial sectors.	- Promotion of public research institutions, especially universities.	- Convergence between nanotechnolog y, advanced materials, and manufacturing.	- Using digital technologies in the R&D of new materials.

Source: Adapted from Bellucci, 2019.

7. Elements of Design Thinking when Discussing the Results

To confirm with the stakeholders (target audience) the main characteristics to be suggested for the elaboration of a National Plan for Advanced Materials for Brazil, the following intervention strategies were outlined, based on the Design Thinking methodology (BROWN, 2017): (i) interviews with strategic partners; and (ii) prototyping and ideation using digital tools.

7.1. Interviews with Experts

To gather a more detailed perception of the needs of end-users in the field of advanced materials, a cycle of interviews was conducted with experts in the field, considering the three branches of the triple helix (academy, government, and business). During the interview cycle, the most relevant findings are associated with: (i) the limited knowledge of the production chain and product life cycle; (ii) the training of human resources at undergraduate and graduate levels with few market-related technical skills; (iii) technology-based ventures whose main market is only domestic; (iv) identification of disruptive and future-bearing fields that need to be fostered by the State; (v) Innovation Centers with low capacity to support and instruct public and private partners in the development of the partnership; and others.

7.2. Prototyping and Ideation with Digital Tools

With the intention to (i) present and discuss the main concepts and strategies associated with the elaboration of the National Plan; (ii) to hastily disseminate and simplify the understanding of the main concepts of the National Plan; and (iii) to disseminate the actions, programs, projects and initiatives conceived for the field of advanced materials, the following were internally prototyped, not institutionally by the MCTIC, a web page 1, an application, based on the web page and graphic animation2, all using free tools available for the community. The main learning associated with prototyping was the possibility of synthesizing the initial structure of the National Plan and simplifying the understanding of the Plan by the main stakeholders.

7.3. Main Trends, Characteristics, and Identified Opportunities

Based on the analysis of the main national and international trends in the field of Advanced Materials, the results of the interviews and ideation actions, their adherence to the national context and Brazil's current opportunities and challenges (Bellucci, 2019), the main suggestions for the subject are presented below.

- Interaction between the Academy and the Private Sector: Considering the challenging scenario of the national macroeconomics, and also taking into account that the field of Advanced Materials is cross-sectional and capable of adding value to national technologies, the national public actions in this field should generate a robust knowledge base and be aligned with the needs of the private sector, while favoring the emergence of innovative technology-based enterprises.
- Specialized Human Resources: Public actions in the field of advanced materials should collaborate to (i) increase the percentage of our society with college degrees, extending to the field of materials; (ii) encourage training and the creation of favorable conditions for technology-based entrepreneurship; and (iii) create a favorable environment for the inclusion of master degree and Ph.D. holders in tech-related national companies.
- Digital Technologies: Considering the quick and disruptive evolution of digital technologies in recent years (high-performance computing, big data, Internet of Things, machine learning, and others), its use should accelerate, reduce costs and risks associated with technological development in the field of advanced materials.
- International Cooperation: This is a strategic structuring axis for public actions in the field of advanced materials, with the potential to accelerate national technological development in fields of interest, promote the exchange and internationalization of knowledge and innovative practices.
- Fields for the Future: Considering the subject matters identified in the international national plans for advanced materials, the main fields are (i) aerospace and defense; (ii) energy; (iii) health and biotechnology; and (iv) nanotechnology and nanomaterials. It should be emphasized that there are opportunities in emerging fields, such as metamaterials, high-entropy materials, multifunctional materials, materials with self-renewal capacity, materials for targeted diagnosis and therapy, carbon derivatives (graphene, fullerenes, and carbon nanotubes), rare earth, among others.

[1] Web page available at: https://fsbellucci.wixsite.com/material

[2] Graphic Animation available at: https://videos.mysimpleshow.com/eQWLku7Fnn

- National Biodiversity: Brazil is a continental-sized country, with singular biodiversity (flora, fauna, and biomes) in the world, encompassing 20% of the total number of species on Earth. National biodiversity is a great competitive advantage for the country, albeit barely explored, with unique potential for the discovery of new materials and their properties.
- Strategic Mineral Resources: A large share of Brazil's trade balance is associated with the export of raw materials of mineral origin with low added value, while also having a large part of the world's reserves of various strategic minerals. It is necessary to devise programs and policies to add value to exports of national mineral resources.
- Overcoming Social Issues in Brazil: Social issues such as poverty, low access to drinking water, malnutrition, limited access to health, inadequate basic sanitation, among others, are obstacles to be overcome in Brazil, and the State should provide basic public policies to do so. The field of advanced materials shows the potential to add value, reduce costs, and disseminate technological solutions to different social issues.

8. Final Considerations

When considering the strategic relevance of the field of advanced materials for the academic, social, and business sectors, an analysis of public policies and prospective studies in this field was conducted to identify the main national and international characteristics and trends in the field of advanced materials. As the main outcome of this study, the Brazilian Ministry of Science, Technology, Innovation and Communications (MCTIC) published in 2019 the S, T&I Action Plan for Convergent and Enabling Technologies, volume III – Advanced Materials (MCTIC, 2019), based on 07 (seven) axes or strategic actions (institutionalization, information systematization), human resources and entrepreneurship, ICT-company interaction, international cooperation, digital technologies, and disruptive topics), for which guidelines have been proposed to be conducted in the programs and activities carried out by the key players of Brazil's National System of Science, Technology, and Innovation in the field of advanced materials.

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