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EXPLORING INNOVATION OPPORTUNITIES IN ENERGY HARVESTING USING FUNCTIONAL MODELING APPROACHES

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ABSTRACT

Energy harvesting is a promising and evolving field of research capable of supplying power to systems in a broad range of applications. Energy harvesting encompasses many distinct technologies, including photovoltaic panels, wind turbines, kinetic motion harvesters, and thermal generators. Each technology utilizes different processes to transform energy from the environment into usable electrical energy. As such, there are many analogous functions and processes that are common or similar across the various domains. To leverage and understand these functions and processes, functional modeling approaches are needed to identify these similarities and functions ripe for innovation in new systems.

This paper describes a method for modeling the functional architectures of a sample set of energy harvesters, using a functional common basis from the literature. Vector space analysis is used to identify patterns and correlations in the use of functions across different products and energy-harvesting domains in the sample set. The resulting analysis indicates that systems in the same domain usually have very similar function structures, differing only by the addition or removal of a few driving or supporting functions. Systems in different domains also typically have similar structures, with the substitution of different material and energy flows into the system. A generalized functional model for energy harvesting is described, along with possible design ramifications and key opportunities to innovate. Several recommendations are given for the continued development and improvement of the functional common basis and, more generally, functional modeling methodologies. These include improved standardization and explanation of abstract functions, such as blending with the environment, and of organizational conventions to improve consistency.

KEYWORDS

Energy harvesting, energy scavenging, renewable energy, functional modeling, function structures, functional common basis, vibration harvesting, solar energy, wind energy

1. INTRODUCTION

The concept of “innovation” currently receives much attention in the popular media, in policy statements [1], and in the design research community [2]. Innovation can be defined in multiple ways. For this paper, we define innovation as the process by which a novel product or system is conceived and realized intentionally to address a human need. In the innovation of new technologies and products, many techniques are available to assist the designer. Some techniques facilitate a better understanding of the design problem, customer needs, and technical specifications, such as QFD [3]. Others identify and offer solutions to inherent conflicts or tradeoffs, such as the Theory or Inventive Problem Solving (TIPS) [4,5]. This paper examines a specific field, energy harvesting, and how design in this area can be aided through functional modeling. Generalizations regarding functional modeling are developed based on this examination.

1.1 ENERGY HARVESTING

Energy harvesting is any process by which freely available energy from external sources is captured *in situ* (on location) and converted into usable electrical energy for local use. This process is in contrast to most electrical power production, where energy is captured on a large scale through centralized fossil fuel, hydroelectric, or nuclear plants and then distributed through AC grid power or replaceable batteries. Energy harvesting harnesses power that otherwise would have been wasted. Among the most common types of energy harvesters are wind turbines and solar harvesters (photovoltaic panels and solar heat engines). Other types under development include systems for harnessing vibration or movement (from machinery, human movement, structures, etc.), thermal gradients, acoustic energy, and electromagnetic energy (primarily ambient radio waves).

1.2 INNOVATION AND DRIVING FUNCTIONS

Substantial research has been conducted regarding how to forecast or predict innovation [6-10]. Industry leaders can make fortunes based on their understanding of when and where innovation is likely to take place. Innovation can occur at varying degrees of significance. Altshuller [5] identified several Levels of Invention, ranging from minor parametric changes to new discoveries in underlying science. In developing energy harvesting, one of two design paths may be followed. The designer may seek to innovate original or novel core technologies, such as a drastically more efficient photovoltaic panel from a never-before-seen material. This direction of research can lead to cutting-edge advances in overall technology, with both high cost and high pay-off. Another avenue of design that is often attractive is to utilize existing core technology and focus solely on the driving system functions. These driving functions typically call for inventive ideas or make use of more established technology, allowing the designer to entertain design changes with greater freedom and at lower cost. Although the resulting concept will be limited by the fundamental restrictions of the core technology, it will still be capable of great advances in efficiency and functionality, which can then be further improved over the long term by subsequent improvements in the core technology. These possible opportunities of innovation in driving functions are low-hanging fruit that can be quickly and easily incorporated into design without the need for extensive research.

Before conducting the research outlined in this paper, we hypothesized the following as the primary driving functions of an energy-harvesting system:

- Concentrate/Direct
- Capture/Collect
- Transform/Amplify
- Convert to Electrical Energy (core function)
- Rectify/Process
- Condition
- Store (short-term and long-term)
- Attach to Environment
- Blend with Environment (visually, etc.)

Each of these driving functions may present numerous opportunities for innovation and improvement. These functions can often be broken down into groups of sub-functions, which may vary substantially from system to system. By identifying these sub-functions and how they can be improved, modified or rearranged, the designer gains access to a set of specific areas that can be targeted for redesign and innovation.

1.3 FUNCTIONAL MODELING

Functional modeling is a process whereby the overall intended behavior of a system is broken down into an architecture or schematic of sub-functions. Functional models can vary in their resolution, from generalized black-box diagrams identifying the input, primary function, and resulting output of the system, to specific diagrams outlining every component, physical phenomenon, and action.

Functional modeling has been identified as a critical step in the design process [11,12] and has been included in many well-known design methodologies [3,13-14] as a means to understand the underlying mechanics of complicated systems, how the sub-functions relate to customer needs and constraints, and how to improve these relationships in future design. To facilitate commonality and better communication among designers using functional modeling, a common basis or taxonomy can be used. The functional common basis developed from efforts by Stone, Wood, Szykman, and others [3,15-18] gives a set of generalized terms describing energies, materials, signals, and functions applicable to any system of interest. The use of these generalized descriptors allows consistent comparisons of different systems and the models of different designers.

By using functional modeling to analyze energy-harvesting systems, we can identify the functions that comprise the systems' core technologies (primarily the method of energy conversion to electricity). The other functions in the models can then be identified as driving functions ripe for innovation, and designers can focus on rearranging or altering the existing framework to enhance or create new functionality.

2. FUNCTIONAL ANALYSIS METHODOLOGY

This paper addresses several ways functional modeling can be used in the design process, as applied to the field of energy harvesting. First, representative energy-harvesting products were selected, and functional models were created for each system in the set. These models were used to gain insight both quantitatively and qualitatively.

The functional models were evaluated quantitatively by compiling the results in a vector-space repository [19-21]. By performing normalization and matrix manipulation steps, matrices were formed that illustrate correlations among products and among functions.

The functional models were also evaluated qualitatively by comparing their organization and identifying key modules and functions characteristic of different types of harvesters and of harvesters in general.

2.1 CHOICE OF ENERGY HARVESTING SYSTEMS

Thirty-nine energy-harvesting systems were chosen for this study. They consist of nine inductive (electromagnetic) vibration harvesters, six piezoelectric vibration harvesters, six wind harvesters, three ocean-current or wave harvesters, six solar harvesters, five thermal harvesters, and four hybrid harvesters that make use of two or more of the other technologies. These systems are a mix of existing commercial products and research prototypes in development. An effort was made to include a representative sampling of typical harvester designs. For example, the selected systems for wind harvesting include two different vertical-axis wind turbines, two horizontal-axis wind turbines, and two systems that use vortices to exploit a flapping or vibrating action.

2.2 GENERATING FUNCTIONAL MODELS

Following the selection of sample energy-harvesting systems, functional models were created by the authors using the functional common basis (future studies will examine models developed by others, as well). By using this terminology, we can convert application-specific terminology into standardized descriptions. For example, one might describe some of the functions of a kinetic flashlight (which uses induction to harvest vibration) as the following:

- Accept the user’s hand
- Convert motion from the hand into relative motion between the magnet and coil
- Convert kinetic energy into a changing magnetic field and then into a voltage
- Condition the voltage by storing it in a capacitor
- Convert the electricity into light
- Transmit the light

These same functions, converted to the functional common basis, would read as the following:

- Import human
- Convert human energy to translational mechanical energy
- Convert translational ME to magnetic energy
- Convert magnetic energy to electrical energy
- Change electrical energy
- Store electrical energy
- Supply electrical energy
- Convert EE to electromagnetic energy
- Transfer electromagnetic energy
- Export electromagnetic energy

This yields a function structure with components that are not application-specific and can be more readily compared with functional models for systems across diverse domains.

2.3 PRODUCT REPOSITORY

A typical functional model may contain a large number of different functions, and it may even contain the same function numerous times in slightly different capacities. To distill this large amount of information, the functions of each system can be summarized in vector form. For example, if the possible functions are {import, export, transfer, change, convert, position} and a particular system contains the functions {import, export, convert}, then a binary vector representation of this system would be {1,1,0,0,1,0}. This simple binary representation was used in this study. Additional insights may be gained through more in-depth breakdown of the functions, such as delineating the object of the function (e.g. “transfer mechanical energy” versus “transfer electrical energy”) or by weighting the functions based on the strength of their relationships with key customer needs [19].

A product repository was formed by compiling the binary vectors for all 39 systems. This resulted in a matrix with each row listing an energy-harvesting system and each column listing a function, material, energy, or signal from the functional common basis. For brevity and clarity, only those members of the basis that were found in at least one harvester were included in the matrix (i.e. no columns were empty).

2.4 VECTOR SPACE ANALYSIS

To analyze the product repository, we used a vector space analysis similar to that used previously by Stone, et al. [19], McAdams, et al. [20], and Weaver, et al. [21]. Two techniques were used in this analysis. For the first technique, each row was normalized by the square root of the number of functions in the system. This prevented skewing from systems with abnormally large or small numbers of functions. By post-multiplying this matrix by its transpose, a square matrix was formed that has the list of products on both the rows and the columns. Because of the square-root normalization, the diagonal entries became unity, and the off-diagonal entries describe the relative similarity between the functional models of the energy harvesters in corresponding rows and columns. This procedure is illustrated by Eq. 1.

$$P_{ab} = \frac{1}{W_a}\frac{1}{W_b}\sum_{i=1}^{n}\left(A_{ai}A_{bi}\right), \quad \text{where} \quad W_a = \sqrt{\sum_{k=1}^{n}\left(A_{ai}\right)}, W_b = \sqrt{\sum_{k=1}^{n}\left(A_{bi}\right)} \qquad \text{Eq. 1}$$

For the second technique, each column was normalized by the square root of the number of systems exhibiting the function. Then, by pre-multiplying the matrix by its transpose, a square matrix was formed that lists the functions, materials, energies, and signals along both the rows and columns (Eq. 2). As in the previous example, the diagonal entries became unity. Each off-diagonal entry gives the correlation between the two functions or flows, i.e. how often the pair of descriptors appears together in the same system.

$$F_{ab} = \frac{1}{W_a}\frac{1}{W_b}\sum_{i=1}^{n}(A_{ia}A_{ib}), \quad where \quad W_a = \sqrt{\sum_{k=1}^{n}(A_{ia})}, W_b = \sqrt{\sum_{k=1}^{n}(A_{ib})}$$

Eq. 2.

The result of these two techniques is two large matrices that provide insights into the relationships among the examined systems. The first matrix illustrates the functional similarities among the energy harvesting systems, and the second matrix shows typical relationships among the functions and flows found in the systems.

2.5 FINDING KEY MODULES AND FUNCTIONS

In addition to the quantitative procedure described above, the functional models were evaluated qualitatively to identify observable trends in how functions, modules (groups of functions acting together on a common material, energy, or signal flow), and overall functional architectures are used in energy harvesting. In particular, the completed functional models were compared to the list of hypothesized driving functions described in Section 1.2.

3. DISCUSSION OF RESULTS

A product repository was formed from 39 energy-harvesting systems and their included functions and flows. The sampled systems have very diverse functions and flows. Out of 14 possible types of energy, 6 types of materials, 2 types of signals, and 21 distinct functions, the product repository included examples of 10 energies, 4 materials, and all possible signals and functions. Thus the total dimensionality of the repository was 37 out of a possible 43 descriptors. The energy-harvesting systems tended to individually be complex as well. The simplest harvester, a thin-film photovoltaic panel with no power conditioning or storage capabilities, utilized 8 distinct functions, several of which appeared multiple times. One of the most complex systems, the HYmini (Fig. 1), included 18 distinct functions, 3 types of materiasl, 7 types of energy, and both types of signals. This system appears simple, but involves several parallel charging options (wind turbine, solar panel, hand crank, bicycle-powered dynamo, and plugging into AC or DC power sources), each with its own power conversion functionality.

Figure 1. HYmini universal charger [22]

Of the functions involved in energy harvesting, the following functions were used at least once in every system: import, export, separate, transfer, and convert. Other frequently used functions include change, position, guide, and secure. Commonly used materials include solid objects, humans, and gas. Common forms of energy include light energy (solar power, status signals, and visual appearance) and electrical energy (the necessary output of energy harvesting), with an even distribution of many other forms of energy like magnetic energy, mechanical energy, pneumatic energy, and human energy.

3.1 FUNCTIONAL SIMILARITIES

Normalizing the product repository and post-multiplying by its transpose yields a 39x39 matrix correlating each energy-harvesting system to the other systems. This product-product matrix is found in Appendix A. Off-diagonal entries show the functional similarity between two systems. In the sample systems, this degree of similarity ranges from 50% to 97%. From this product-product matrix, the following conclusions can be drawn:

- Wind harvesters showed high degrees of functional similarity with other wind harvesters, ranging from 80% to 96%.
- Thermal harvesters showed high levels of similarity as well. With one exception, similarities ranged from 83% to 97%. The exception, the Seiko Thermic watch, shared similarities of 69% to 73% with other thermal harvesters, but showed higher similarity with other human-related products, such as kinetic and solar-powered watches, kinetic flashlights, and hand-held harvesters like the HYmini.
- Vibration, wave, and solar harvesters exhibit a wider range of high and low similarity within their respective domains. These levels range from 60% to 96%.
- High degrees of similarity between differing domains include the following combinations:
    - Solar harvesters with hybrid systems (which all include solar capability)
    - Wind harvesters with hybrid systems (one hybrid system includes a gas-based sterling engine heated from solar power; the others include wind turbines)
    - Human-related harvesters (watches, flashlights, and handheld wind turbines)
- Low degrees of similarity between differing domains include the following combinations:
    - Wave harvesters and vibration harvesters
    - Solar harvesters and wave harvesters
    - Solar harvesters and wind harvesters
    - Vibration harvesters and thermal harvesters

3.2 FUNCTION AND FLOW COMBINATIONS

Normalizing the product repository and pre-multiplying by its transpose yields a 37x37 matrix relating the relevant members of the functional common basis (Appendix B). In this function-function matrix, as in the previous example, the diagonal terms have been normalized to unity. The off-diagonal terms indicate the relative strength of correlation between the row and column functions or flows, i.e. how likely they are to appear together in a functional model. As described previously, several functions are near universal among the sampled systems, such as “import,” “export,” “transfer,” and “convert.” This prevalence creates strong correlation among all these functions that can overshadow other relationships shown in the function-function matrix.

In addition to these most common functions, several common groupings can also be identified that often occur together:

- Store, supply, sense, indicate, actuate, regulate, and signal
- Guide, secure, sense, position, secure, and solid
- Human and human energy
- Gas and pneumatic energy
- Liquid and hydraulic energy

The interactions among the materials and energies were below the average for function correlations, meaning that the individual flows were less likely to be found with other flows. The combinations identified above are exceptions to this, as is solid material, which occurred with other materials and energies slightly more than average.

3.3 COMMON MODULES AND COMPARISON TO HYPOTHESIZED DRIVING FUNCTIONS

Examination of the functional models created for the ensample energy-harvesting systems produced several insights. Within each domain (e.g. vibration harvesting), functional models follow very similar structures. The predominant changes are addition or subtraction of beneficial but non-essential functionality. In addition, these structures largely remain consistent when comparing across differing domains, as well. Here, the major shifts occur by substituting different material and energy flows into similar function architectures.

As an example, we can consider three example systems: the Seiko Kinetic watch (inductive vibration harvesting), a prototype harvester inside the heel of a shoe (piezoelectric vibration harvesting) and the Enviro-Energies vertical-axis wind turbine (wind harvesting). Functional models for these three systems are included in Appendix C.

In the Kinetic watch (Fig. 2), the material flow of interest is the human hand, which carries with it mechanical energy from its motion. Functions acting on this flow include importing the hand, guiding it (through the wristband), positioning it (so the watch is on the wrist facing the right way), separating out some of the mechanical energy for harvesting, and distributing the rest evenly back into the human as reaction forces. Additional functions that occur include guiding the hand back out of the wristband, separating from it, and exporting the hand from the system. The mechanical energy extracted is transmitted to the components of the watch, where it is converted from oscillating motion to rotary motion. A gear system changes the mechanical energy by increasing the rotational velocity and decreasing the torque, after which the mechanical energy is converted to electrical energy by an electromagnetic generator. After the electrical energy is conditioned and smoothed, it is stored and supplied as needed in a battery, with the measured voltage being displayed visually as a battery life gauge. Electricity is then transmitted to the motor and converted back into rotational mechanical energy, which is then changed through the complicated workings of the watch into rotation of the hands on the face. In addition to this entire process, a separate structure exists to describe the visual appearance of the watch, addressing such functions as blending and aesthetics. These functions can be grouped into general modules, including attaching to the environment (the hand), capturing the mechanical energy, directing or filtering it into a two-dimensional oscillation, transforming it into rotational mechanical energy at higher velocity, conversion to electricity, conditioning, storage, blending with the environment, and the application functionality of displaying time.

Figure 2. Seiko Kinetic wristwatch [23]

In the heel-impact shoe vibration harvester (Fig. 3), two material flows are imported: the human foot and the ground. Like the watch, this system uses functions like guide, secure, stabilize, distribute, and separate to describe attachment to the environment (the foot and the ground) and effective collection of mechanical energy for harvesting. After the mechanical energy is isolated, it is transformed by a function sequence very similar to the watch, with the energy directed in the appropriate direction for the piezoelectric ceramic, converted to electricity, rectified and smoothed, stored temporarily, and then exported for use powering low-power electronics or similar applications. The blend functionality is also important here, both visually and indirectly through the even distribution of reaction forces to the foot.

Figure 3. Shoe-mounted piezoelectric harvester [24]

In the Enviro-Energies wind turbine (Fig. 4), the primary material flows are the roof (or other solid structure) and the air, a gas. The roof is subjected to the same attachment oriented functions as in the previous examples, including positioning, securing to, and eventually separating from the roof. The gas is guided and stabilized such that the gas pressure can be converted into rotational mechanical energy. Then, once again, this energy is transmitted, converted to electricity, conditioned, stored, and exported to the application of interest. Blending is an important functionality in this system as well, and is represented in the functional model in the same way.

Figure 4. Enviro-Energies vertical-axis wind turbine [25]

These three systems have different inputs (motion of a hand, forces between a foot and the ground, and relative motion of wind to a structure) but use similar function chains to interface with the environment, prepare the energy for harvesting, extract or collect the energy, and transform the energy into a form most efficient for conversion to electricity. After using the systems' core technologies to make the conversion to electricity, the remaining functionality is close to identical among the three systems, consisting of conditioning the electricity into a state suitable for electronics, storing it until needed, and then supplying it for use in the application. Through the whole process, the visual interaction with the user remains a constant need, including overall visual appearance and visual or tactile status signals.

We propose that energy harvesters in general will embody the following string of overall driving functions:

1. Interface (attach, position, etc.) with environment
2. Direct (filter, concentrate) energy from the environment
3. Separate (extract, collect, capture) energy
4. Transform (amplify, change) energy into form ready for conversion
5. Convert energy to electrical energy
6. Condition (rectify, process, smooth, change) electrical energy for storage or use
7. Store electrical energy
8. Supply electrical energy to application
9. Interface (interaction with light, status signals, visual/tactile/audio feedback) with user

The actual common basis functions included in each step may vary, depending on, for example, whether the direction and transformation of incoming energy needs to be actively controlled by the user or occurs passively. These steps may be complicated or simple, but will occur in some form in any energy-harvesting process.

3.4 APPLICATIONS IN DESIGN

The insights gained through functional modeling can have direct application to the design of new energy harvesters. Each of the functions described above presents an opportunity for innovation:

1. *Interface with environment*: Improve energy flow into the system through closer coupling with the environment.
2. *Direct energy from environment*: Instead of capturing only the portion of environmental energy directly available, redirect and concentrate previously unused energy into the system. For example, a horizontal-axis wind turbine captures energy from just one direction. A vertical-axis turbine can capture wind energy from any direction in the horizontal plane.
3. *Separate energy*: Increase efficiency of energy collection or extraction.
4. *Transform energy*: Amplify conjugates or otherwise alter energy into a form more conducive to conversion to electricity (e.g. increasing velocity, amplitude, or frequency).
5. *Convert energy*: This is the system's core technology and is more difficult to improve without basic research
6. *Condition electrical energy*: Use active control to improve efficiency beyond that of passive rectifying and smoothing techniques.
7. *Store electrical energy*: Consider different forms of electrical storage (batteries, capacitors, ultra-capacitors, etc.) and non-electrical storage (flywheels, springs, fluid capacitances, etc.) to increase efficiency and reduce losses in short-term and long-term storage.
8. *Supply electrical energy to application*: Increase efficiency and ease of use through sensing power needs and actively optimizing power delivery.
9. *Interface with user*: Enhance user control and status feedback, and assess ways to integrate better aesthetics, usability, and blending.

As designers becomes familiar with these driving functions, their roles in energy harvesting, and the opportunities available for innovation, concept generation can be focused on innovative solutions to these smaller design problems. Many of these driving functions are largely independent, meaning that existing solutions and analogies can be borrowed from systems in vastly different fields. These sub-solutions can then be combined into working architectures customized for the specific applications at hand.

In many autonomous harvesters, the main goal of the driving functions is simply to capture and convert the available energy as efficiently as possible. However, with energy harvesters that interact with humans or animals, a second main focus is to actually encourage the contribution of more energy. This is often done by giving positive visual feedback to the user. For example, the Seiko Kinetic Direct Drive watch is powered primarily through normal body motion. However, power can also be generated manually by winding the crown. A colorful gauge on the face acts like a tachometer as the crown is wound, inspiring the user to see how much power can be generated. The Sustainable Dance Floor [26] generates power from the pressure and vibration of dancing partygoers. It encourages participation through LED lights on the floor tiles and a large LED meter near the DJ. The Toyota Prius, while not strictly an energy harvester, employs a very similar method by giving real-time visual feedback of power flow between the gas engine, electric motor, batteries, and regenerative brakes, as well as displaying instantaneous miles per gallon estimates and giving the option for “power,” “eco,” or “EV” (electric vehicle) settings.

3.5 INSIGHTS INTO FUNCTIONAL MODELING

This study allows further review of functional modeling, and more specifically the functional common basis, as a tool in design. In using functional modeling, one common complaint is the non-uniformity in language, resolution, and conventions. The functional common basis makes many improvements in providing a common vocabulary. Much of the remaining confusion concerning functional modeling seems to come from difficulty standardizing and explaining organizational conventions and terminology.

For example, mechanical energy and human energy are two energy flows identified in the functional common basis. These two energies are physically similar (solids exerting forces and velocities), but it is useful to separate them due to differing relationships to customer needs (ergonomics and user safety introduce additional needs and functionality into human-related systems). This separation, however, often requires a conversion at some point from human energy to mechanical energy. There is currently no standard convention to model when and how this occurs. Does the human energy become mechanical energy the instant it enters the system with the human? When it is transferred from the human into the structure of the product? When it is converted into “useful” motion such as shaft work? Small variations such as these are irrelevant when working with a single functional model, but make it difficult to effectively compare functional models of different systems and from different designers, just as non-standard function terminology has in the past.

Beneficial future research in this area would more carefully clarify function and flow definitions and give standardized examples of common sources of confusion. Some of this information is available in previous literature, but much is merely implied or has been explained orally. A straightforward introduction and guide to functional modeling using the functional common basis would be an invaluable tool to designers not familiar with the process.

4. CONCLUSION

Functional modeling can be an excellent tool for understanding and creating new designs. By applying functional modeling to energy harvesting, the designer can identify key opportunities for innovation in the driving functions of the systems. Through the modeling and analysis of 39 example energy harvesters, a close functional relationship among such systems was observed and quantified. Systems in the same domain typically follow very similar function structures, differing only by the addition or subtraction of a few supplementary functions. Systems in different harvesting domains usually employ similar functions as well, differing by the material and energy flows that interact with the system. A generalized energy harvester can be described by the nine main functions identified in Section 3.3 and 3.4. With the exception of the core energy conversion function, which may require extensive basic research to bring substantial improvement, each of the functions present clear opportunities for innovation.

The identification of these functions can also assist in the design of new systems by facilitating design by analogy with other domains. For example, solar harvesters often make use of mirrors and lenses to direct energy (redirecting and concentrating it). How would this be accomplished in the vibration domain? In the thermal domain? Because these other domains make use of different materials and energies, it is beneficial to have foreknowledge of what functions may be necessary and how these might be practically employed in each domain. Familiarity with typical functional models of energy harvesters across domains enables greater innovation through identification of driving functions of interest and how they relate to equivalent functions in other energy domains.

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APPENDIX A: PRODUCT-PRODUCT MATRIX

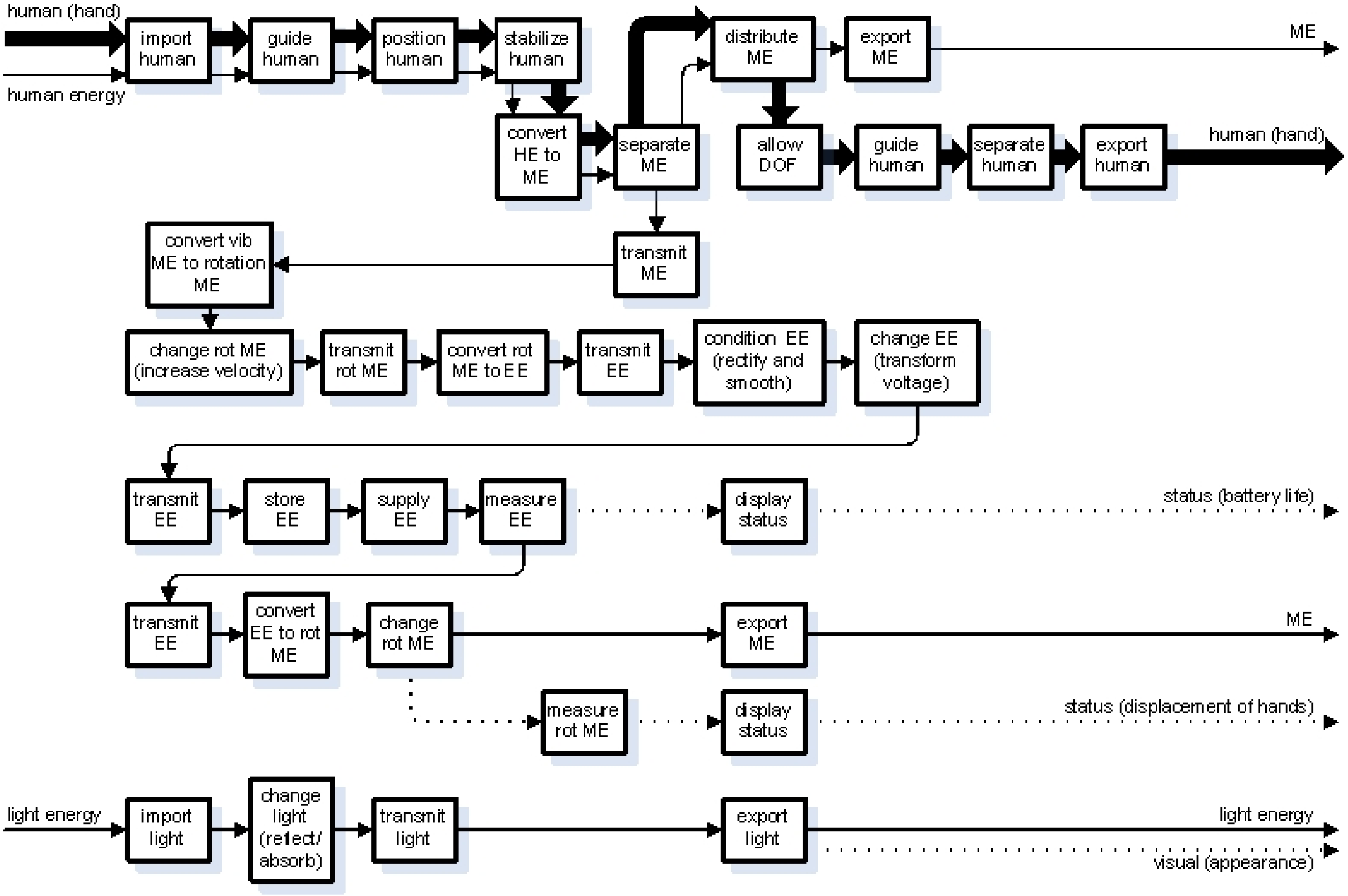
	Perpetuum FSH/C	Enocean Eco 100	Clarkson U prototype	Michigan U PFIG	U Texas prototype	Seiko Kinetic watch	AA battery harvester	Soccket	Kinetic flashlight	MIDE Volture	Bistable buckling harvester	Heel-impact shoe harvester	Innowattech road/rail	Piezo backpack straps	U Texas prototype	WindTamer	Leviathan	Enviro Energies	Four Seasons	Humdinger Wind Belt	Michigan U piezo flag	Nova Energy tuna turbine	Columbia Power Manta buoy	Wing Wave Generator	Solar heat engine w/ mirrors	Tracking system	Inflatable mat	Big Belly trash compactor	Transparent film on window	Seiko Solar watch	Seiko Thermic watch	Enocean ECT 310 Perpetuum	Micropelt TE-power probe	Micropelt TE-power ring	Micropelt STM-PEM	Solar powered Sterling engine	Solar/wind streetlamp	Kinesis wind/solar	Hymini wind/solar/crank
Perpetuum FSH/C	***1.00***	0.85	0.87	0.83	0.83	0.62	0.79	0.64	0.65	0.85	0.87	0.72	0.73	0.63	0.79	0.75	0.79	0.77	0.79	0.88	0.85	0.70	0.67	0.73	0.70	0.67	0.59	0.62	0.69	0.58	0.55	0.73	0.69	0.71	0.73	0.79	0.72	0.63	0.66
Enocean Eco 100	0.85	***1.00***	0.79	0.76	0.75	0.75	0.77	0.74	0.79	0.72	0.73	0.85	0.73	0.74	0.72	0.84	0.82	0.80	0.77	0.80	0.78	0.79	0.72	0.78	0.74	0.71	0.64	0.70	0.76	0.72	0.68	0.72	0.74	0.76	0.78	0.77	0.71	0.71	0.73
Clarkson U prototype	0.87	0.79	***1.00***	0.82	0.95	0.72	0.87	0.60	0.70	0.84	0.75	0.72	0.69	0.60	0.91	0.75	0.78	0.72	0.73	0.81	0.84	0.70	0.58	0.69	0.79	0.76	0.61	0.71	0.60	0.68	0.69	0.68	0.70	0.72	0.74	0.78	0.80	0.76	0.78
Michigan U PFIG	0.83	0.76	0.82	***1.00***	0.88	0.64	0.84	0.77	0.67	0.81	0.89	0.73	0.83	0.72	0.89	0.72	0.70	0.78	0.80	0.83	0.76	0.77	0.70	0.76	0.72	0.73	0.62	0.68	0.67	0.61	0.62	0.75	0.72	0.74	0.76	0.70	0.73	0.69	0.71
U Texas prototype	0.83	0.75	0.95	0.88	***1.00***	0.77	0.91	0.67	0.76	0.90	0.83	0.68	0.77	0.67	0.96	0.71	0.74	0.77	0.79	0.78	0.80	0.67	0.65	0.65	0.84	0.81	0.67	0.75	0.57	0.74	0.74	0.74	0.67	0.68	0.70	0.74	0.85	0.81	0.82
Seiko Kinetic watch	0.62	0.75	0.72	0.64	0.77	***1.00***	0.82	0.80	0.96	0.71	0.62	0.77	0.62	0.82	0.78	0.75	0.74	0.77	0.74	0.58	0.61	0.67	0.75	0.61	0.83	0.80	0.75	0.85	0.53	0.94	0.89	0.61	0.54	0.60	0.57	0.70	0.80	0.91	0.88
AA battery harvester	0.79	0.77	0.87	0.84	0.91	0.82	***1.00***	0.78	0.85	0.82	0.79	0.78	0.74	0.74	0.92	0.68	0.71	0.74	0.76	0.74	0.77	0.64	0.63	0.63	0.81	0.78	0.64	0.80	0.55	0.79	0.79	0.71	0.64	0.66	0.67	0.76	0.82	0.85	0.86
Soccket	0.64	0.74	0.60	0.77	0.67	0.80	0.78	***1.00***	0.84	0.63	0.69	0.81	0.64	0.81	0.73	0.70	0.63	0.76	0.73	0.65	0.58	0.70	0.74	0.69	0.65	0.67	0.75	0.79	0.66	0.78	0.73	0.59	0.55	0.56	0.58	0.63	0.67	0.76	0.73
Kinetic flashlight	0.65	0.79	0.70	0.67	0.76	0.96	0.85	0.84	***1.00***	0.69	0.65	0.80	0.65	0.86	0.77	0.74	0.73	0.76	0.73	0.61	0.64	0.65	0.79	0.59	0.78	0.75	0.74	0.81	0.56	0.94	0.88	0.64	0.56	0.57	0.59	0.68	0.75	0.87	0.84
MIDE Volture	0.85	0.72	0.84	0.81	0.90	0.71	0.82	0.63	0.69	***1.00***	0.91	0.65	0.79	0.69	0.87	0.69	0.72	0.75	0.77	0.74	0.83	0.59	0.67	0.61	0.84	0.80	0.74	0.74	0.63	0.72	0.68	0.77	0.63	0.65	0.67	0.72	0.80	0.71	0.73
Bistable buckling harvester	0.87	0.73	0.75	0.89	0.83	0.62	0.79	0.69	0.65	0.91	***1.00***	0.66	0.87	0.75	0.79	0.65	0.68	0.77	0.79	0.81	0.79	0.65	0.73	0.67	0.75	0.72	0.65	0.67	0.69	0.63	0.60	0.79	0.69	0.71	0.73	0.68	0.72	0.63	0.66
Heel-impact shoe harvester	0.72	0.85	0.72	0.73	0.68	0.77	0.78	0.81	0.80	0.65	0.66	***1.00***	0.66	0.78	0.74	0.80	0.74	0.73	0.70	0.67	0.70	0.80	0.65	0.70	0.71	0.72	0.71	0.79	0.74	0.78	0.78	0.70	0.72	0.73	0.75	0.70	0.64	0.77	0.78
Innowattech road/rail	0.73	0.73	0.69	0.83	0.77	0.62	0.74	0.64	0.65	0.79	0.87	0.66	***1.00***	0.75	0.74	0.65	0.68	0.72	0.73	0.75	0.73	0.65	0.67	0.67	0.75	0.72	0.59	0.62	0.62	0.63	0.60	0.73	0.69	0.71	0.73	0.62	0.67	0.63	0.66
Piezo backpack straps	0.63	0.74	0.60	0.72	0.67	0.82	0.74	0.81	0.86	0.69	0.75	0.78	0.75	***1.00***	0.64	0.66	0.69	0.72	0.74	0.65	0.63	0.66	0.80	0.63	0.71	0.68	0.66	0.72	0.58	0.84	0.79	0.69	0.65	0.67	0.69	0.58	0.63	0.78	0.75
U Texas prototype	0.79	0.72	0.91	0.89	0.96	0.78	0.92	0.73	0.77	0.87	0.79	0.74	0.74	0.64	***1.00***	0.72	0.71	0.74	0.76	0.74	0.77	0.68	0.63	0.67	0.85	0.86	0.72	0.80	0.60	0.75	0.75	0.71	0.64	0.66	0.67	0.76	0.86	0.81	0.82
WindTamer	0.75	0.84	0.75	0.72	0.71	0.75	0.68	0.70	0.74	0.69	0.65	0.80	0.65	0.66	0.72	***1.00***	0.96	0.89	0.86	0.81	0.84	0.83	0.69	0.79	0.74	0.75	0.78	0.74	0.72	0.68	0.72	0.73	0.75	0.81	0.79	0.86	0.79	0.79	0.80
Leviathan	0.79	0.82	0.78	0.70	0.74	0.74	0.71	0.63	0.73	0.72	0.68	0.74	0.68	0.69	0.71	0.96	***1.00***	0.88	0.90	0.85	0.87	0.77	0.67	0.77	0.77	0.74	0.73	0.69	0.64	0.67	0.71	0.76	0.78	0.85	0.82	0.90	0.83	0.82	0.84
Enviro Energies	0.77	0.80	0.72	0.78	0.77	0.77	0.74	0.76	0.76	0.75	0.77	0.73	0.72	0.72	0.74	0.89	0.88	***1.00***	0.98	0.83	0.80	0.76	0.75	0.70	0.76	0.72	0.76	0.75	0.63	0.70	0.74	0.79	0.72	0.78	0.75	0.84	0.85	0.81	0.82
Four Seasons	0.79	0.77	0.73	0.80	0.79	0.74	0.76	0.73	0.73	0.77	0.79	0.70	0.73	0.74	0.76	0.86	0.90	0.98	***1.00***	0.85	0.82	0.73	0.72	0.72	0.77	0.74	0.73	0.73	0.58	0.67	0.71	0.81	0.73	0.80	0.77	0.86	0.87	0.82	0.84
Humdinger Wind Belt	0.88	0.80	0.81	0.83	0.78	0.58	0.74	0.65	0.61	0.74	0.81	0.67	0.75	0.65	0.74	0.81	0.85	0.83	0.85	***1.00***	0.91	0.71	0.63	0.74	0.66	0.63	0.61	0.59	0.65	0.54	0.61	0.74	0.81	0.83	0.86	0.85	0.78	0.69	0.71
Michigan U piezo flag	0.85	0.78	0.84	0.76	0.80	0.61	0.77	0.58	0.64	0.83	0.79	0.70	0.73	0.63	0.77	0.84	0.87	0.80	0.82	0.91	***1.00***	0.64	0.56	0.67	0.74	0.71	0.69	0.66	0.63	0.63	0.68	0.77	0.79	0.81	0.83	0.87	0.80	0.71	0.73
Nova Energy tuna turbine	0.70	0.79	0.70	0.77	0.67	0.67	0.64	0.70	0.65	0.59	0.65	0.80	0.65	0.66	0.68	0.83	0.77	0.76	0.73	0.71	0.64	***1.00***	0.79	0.88	0.70	0.71	0.65	0.70	0.78	0.64	0.64	0.68	0.84	0.81	0.79	0.73	0.67	0.67	0.72
Columbia Power Manta buoy	0.67	0.72	0.58	0.70	0.65	0.75	0.63	0.74	0.79	0.67	0.73	0.65	0.67	0.80	0.63	0.69	0.67	0.75	0.72	0.63	0.56	0.79	***1.00***	0.72	0.64	0.61	0.69	0.61	0.63	0.72	0.68	0.67	0.69	0.59	0.61	0.57	0.61	0.67	0.65
Wing Wave Generator	0.73	0.78	0.69	0.76	0.65	0.61	0.63	0.69	0.59	0.61	0.67	0.70	0.67	0.63	0.67	0.79	0.77	0.70	0.72	0.74	0.67	0.88	0.72	***1.00***	0.69	0.71	0.59	0.61	0.76	0.53	0.50	0.62	0.79	0.76	0.72	0.72	0.66	0.62	0.65
Solar heat engine w/ mirrors	0.70	0.74	0.79	0.72	0.84	0.83	0.81	0.65	0.78	0.84	0.75	0.71	0.75	0.71	0.85	0.74	0.77	0.76	0.77	0.66	0.74	0.70	0.64	0.69	***1.00***	0.96	0.78	0.85	0.67	0.85	0.80	0.77	0.70	0.77	0.74	0.82	0.92	0.83	0.88
Tracking system	0.67	0.71	0.76	0.73	0.81	0.80	0.78	0.67	0.75	0.80	0.72	0.72	0.72	0.68	0.86	0.75	0.74	0.72	0.74	0.63	0.71	0.71	0.61	0.71	0.96	***1.00***	0.79	0.89	0.69	0.82	0.77	0.79	0.67	0.73	0.71	0.79	0.88	0.79	0.84
Inflatable mat	0.59	0.64	0.61	0.62	0.67	0.75	0.64	0.75	0.74	0.74	0.65	0.71	0.59	0.66	0.72	0.78	0.73	0.76	0.73	0.61	0.69	0.65	0.69	0.59	0.78	0.79	***1.00***	0.77	0.72	0.81	0.84	0.77	0.65	0.67	0.69	0.73	0.79	0.79	0.80
Big Belly trash compactor	0.62	0.70	0.71	0.68	0.75	0.85	0.80	0.79	0.81	0.74	0.67	0.79	0.62	0.72	0.80	0.74	0.69	0.75	0.73	0.59	0.66	0.70	0.61	0.61	0.85	0.89	0.77	***1.00***	0.65	0.87	0.82	0.69	0.58	0.64	0.61	0.73	0.82	0.81	0.85
Transparent film on window	0.69	0.76	0.60	0.67	0.57	0.53	0.55	0.66	0.56	0.63	0.69	0.74	0.62	0.58	0.60	0.72	0.64	0.63	0.58	0.65	0.63	0.78	0.63	0.76	0.67	0.69	0.72	0.65	***1.00***	0.60	0.57	0.70	0.72	0.74	0.76	0.64	0.59	0.51	0.59
Seiko Solar watch	0.58	0.72	0.68	0.61	0.74	0.94	0.79	0.78	0.94	0.72	0.63	0.78	0.63	0.84	0.75	0.68	0.67	0.70	0.67	0.54	0.63	0.64	0.72	0.53	0.85	0.82	0.81	0.87	0.60	***1.00***	0.94	0.67	0.59	0.61	0.63	0.67	0.78	0.85	0.86
Seiko Thermic watch	0.55	0.68	0.69	0.62	0.74	0.89	0.79	0.73	0.88	0.68	0.60	0.78	0.60	0.79	0.75	0.72	0.71	0.74	0.71	0.61	0.68	0.64	0.68	0.50	0.80	0.77	0.84	0.82	0.57	0.94	***1.00***	0.76	0.69	0.71	0.73	0.71	0.81	0.91	0.91
Enocean ECT 310 Perpetuum	0.73	0.72	0.68	0.75	0.74	0.61	0.71	0.59	0.64	0.77	0.79	0.70	0.73	0.69	0.71	0.73	0.76	0.79	0.81	0.74	0.77	0.68	0.67	0.62	0.77	0.79	0.77	0.69	0.70	0.67	0.76	***1.00***	0.83	0.85	0.87	0.76	0.79	0.74	0.80
Micropelt TE-power probe	0.69	0.74	0.70	0.72	0.67	0.54	0.64	0.55	0.56	0.63	0.69	0.72	0.69	0.65	0.64	0.75	0.78	0.72	0.73	0.81	0.79	0.84	0.69	0.79	0.70	0.67	0.65	0.58	0.72	0.59	0.69	0.83	***1.00***	0.92	0.95	0.78	0.72	0.68	0.73
Micropelt TE-power ring	0.71	0.76	0.72	0.74	0.68	0.60	0.66	0.56	0.57	0.65	0.71	0.73	0.71	0.67	0.66	0.81	0.85	0.78	0.80	0.83	0.81	0.81	0.59	0.76	0.77	0.73	0.67	0.64	0.74	0.61	0.71	0.85	0.92	***1.00***	0.97	0.85	0.78	0.74	0.80
Micropelt STM-PEM	0.73	0.78	0.74	0.76	0.70	0.57	0.67	0.58	0.59	0.67	0.73	0.75	0.73	0.69	0.67	0.79	0.82	0.75	0.77	0.86	0.83	0.79	0.61	0.72	0.74	0.71	0.69	0.61	0.76	0.63	0.73	0.87	0.95	0.97	***1.00***	0.82	0.75	0.71	0.77
Solar powered Sterling engine	0.79	0.77	0.78	0.70	0.74	0.70	0.76	0.63	0.68	0.72	0.68	0.70	0.62	0.58	0.76	0.86	0.90	0.84	0.86	0.85	0.87	0.73	0.57	0.72	0.82	0.79	0.73	0.73	0.64	0.67	0.71	0.76	0.78	0.85	0.82	***1.00***	0.92	0.78	0.84
Solar/wind streetlamp	0.72	0.71	0.80	0.73	0.85	0.80	0.82	0.67	0.75	0.80	0.72	0.64	0.67	0.63	0.86	0.79	0.83	0.85	0.87	0.78	0.80	0.67	0.61	0.66	0.92	0.88	0.79	0.82	0.59	0.78	0.81	0.79	0.72	0.78	0.75	0.92	***1.00***	0.87	0.91
Kinesis wind/solar	0.63	0.71	0.76	0.69	0.81	0.91	0.85	0.76	0.87	0.71	0.63	0.77	0.63	0.78	0.81	0.79	0.82	0.81	0.82	0.69	0.71	0.67	0.67	0.62	0.83	0.79	0.79	0.81	0.51	0.85	0.91	0.74	0.68	0.74	0.71	0.78	0.87	***1.00***	0.97
Hymini wind/solar/crank	0.66	0.73	0.78	0.71	0.82	0.88	0.86	0.73	0.84	0.73	0.66	0.78	0.66	0.75	0.82	0.80	0.84	0.82	0.84	0.71	0.73	0.72	0.65	0.65	0.88	0.84	0.80	0.85	0.59	0.86	0.91	0.80	0.73	0.80	0.77	0.84	0.91	0.97	***1.00***

APPENDIX B: FUNCTION-FUNCTION MATRIX

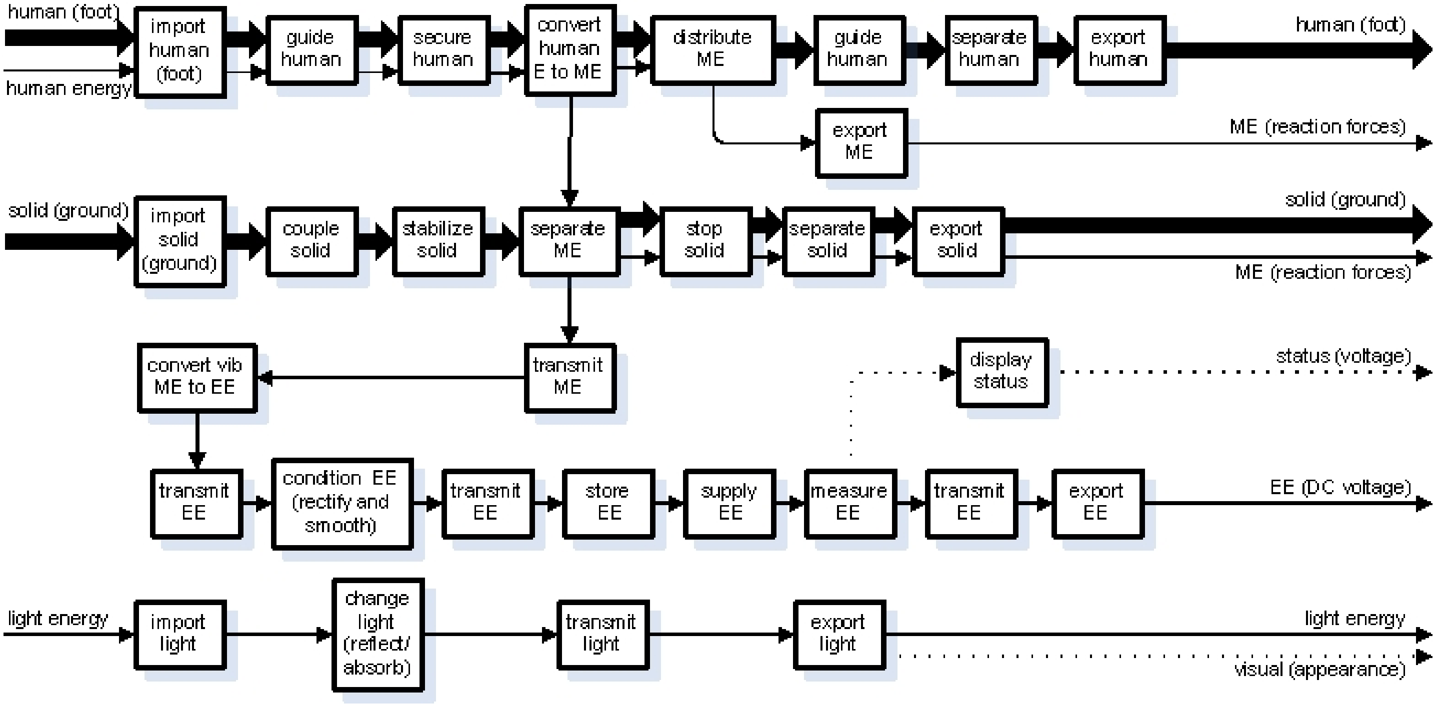
	separate	distribute	import	export	transfer	guide	couple	mix	actuate	regulate	change	stop	convert	store	supply	sense	indicate	process	stabilize	secure	position	solid	human	gas	liquid	human E	rot ME	trans ME	vib ME	pneu E	hyd E	light E	EE	mag E	therm E	status	control
separate	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
distribute	0.77	1.00	0.77	0.77	0.77	0.70	0.50	0.00	0.45	0.45	0.74	0.44	0.77	0.55	0.55	0.57	0.52	0.24	0.66	0.57	0.70	0.62	0.54	0.52	0.42	0.50	0.54	0.61	0.06	0.52	0.42	0.74	0.77	0.44	0.65	0.74	0.51
import	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
export	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
transfer	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
guide	0.91	0.70	0.91	0.91	0.91	1.00	0.61	0.18	0.66	0.57	0.92	0.48	0.91	0.69	0.69	0.76	0.66	0.20	0.64	0.81	0.90	0.83	0.61	0.62	0.27	0.59	0.68	0.52	0.43	0.62	0.27	0.89	0.91	0.75	0.55	0.89	0.71
couple	0.60	0.50	0.60	0.60	0.60	0.61	1.00	0.00	0.50	0.43	0.61	0.32	0.60	0.44	0.44	0.47	0.40	0.15	0.32	0.59	0.63	0.60	0.39	0.47	0.27	0.40	0.28	0.21	0.40	0.47	0.27	0.61	0.60	0.46	0.48	0.61	0.42
mix	0.16	0.00	0.16	0.16	0.16	0.18	0.00	1.00	0.27	0.27	0.16	0.30	0.16	0.20	0.20	0.20	0.25	0.58	0.24	0.18	0.17	0.17	0.29	0.00	0.00	0.30	0.26	0.27	0.00	0.00	0.00	0.16	0.16	0.00	0.26	0.16	0.22
actuate	0.60	0.45	0.60	0.60	0.60	0.66	0.50	0.27	1.00	0.86	0.61	0.24	0.60	0.71	0.71	0.73	0.80	0.31	0.45	0.44	0.63	0.47	0.62	0.27	0.00	0.64	0.48	0.36	0.32	0.27	0.00	0.61	0.60	0.51	0.48	0.61	0.84
regulate	0.60	0.45	0.60	0.60	0.60	0.57	0.43	0.27	0.86	1.00	0.61	0.32	0.60	0.71	0.71	0.73	0.73	0.31	0.45	0.44	0.59	0.51	0.46	0.33	0.00	0.48	0.48	0.36	0.32	0.33	0.00	0.61	0.60	0.40	0.55	0.61	0.84
change	0.99	0.74	0.99	0.99	0.99	0.92	0.61	0.16	0.61	0.61	1.00	0.49	0.99	0.79	0.79	0.83	0.65	0.28	0.67	0.86	0.96	0.90	0.56	0.65	0.32	0.54	0.63	0.56	0.54	0.65	0.32	0.97	0.99	0.76	0.59	0.97	0.73
stop	0.53	0.44	0.53	0.53	0.53	0.48	0.32	0.30	0.24	0.32	0.49	1.00	0.53	0.37	0.37	0.35	0.45	0.35	0.44	0.50	0.36	0.58	0.26	0.15	0.30	0.27	0.39	0.56	0.18	0.15	0.30	0.54	0.53	0.39	0.39	0.54	0.34
convert	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
store	0.78	0.55	0.78	0.78	0.78	0.69	0.44	0.20	0.71	0.71	0.79	0.37	0.78	1.00	1.00	0.72	0.71	0.35	0.64	0.56	0.76	0.64	0.59	0.41	0.10	0.62	0.47	0.49	0.43	0.41	0.10	0.76	0.78	0.57	0.47	0.76	0.68
supply	0.78	0.55	0.78	0.78	0.78	0.69	0.44	0.20	0.71	0.71	0.79	0.37	0.78	1.00	1.00	0.72	0.71	0.35	0.64	0.56	0.76	0.64	0.59	0.41	0.10	0.62	0.47	0.49	0.43	0.41	0.10	0.76	0.78	0.57	0.47	0.76	0.68
sense	0.82	0.57	0.82	0.82	0.82	0.76	0.47	0.20	0.73	0.73	0.83	0.35	0.82	0.72	0.72	1.00	0.74	0.34	0.62	0.72	0.83	0.75	0.57	0.59	0.00	0.53	0.61	0.52	0.41	0.59	0.00	0.83	0.82	0.67	0.51	0.83	0.88
indicate	0.64	0.52	0.64	0.64	0.64	0.66	0.40	0.25	0.80	0.73	0.65	0.45	0.64	0.71	0.71	0.74	1.00	0.29	0.61	0.41	0.59	0.52	0.72	0.38	0.00	0.75	0.52	0.53	0.15	0.38	0.00	0.65	0.64	0.48	0.58	0.65	0.78
process	0.28	0.24	0.28	0.28	0.28	0.20	0.15	0.58	0.31	0.31	0.28	0.35	0.28	0.35	0.35	0.34	0.29	1.00	0.14	0.32	0.29	0.30	0.17	0.14	0.00	0.17	0.30	0.15	0.00	0.14	0.00	0.28	0.28	0.00	0.45	0.28	0.26
stabilize	0.66	0.66	0.66	0.66	0.66	0.64	0.32	0.24	0.45	0.45	0.67	0.44	0.66	0.64	0.64	0.62	0.61	0.14	1.00	0.35	0.61	0.46	0.70	0.49	0.24	0.73	0.56	0.78	0.00	0.49	0.24	0.67	0.66	0.57	0.38	0.67	0.54
secure	0.88	0.57	0.88	0.88	0.88	0.81	0.59	0.18	0.44	0.44	0.86	0.50	0.88	0.56	0.56	0.72	0.41	0.32	0.35	1.00	0.86	0.95	0.26	0.59	0.27	0.22	0.61	0.34	0.61	0.59	0.27	0.86	0.88	0.66	0.57	0.86	0.57
position	0.95	0.70	0.95	0.95	0.95	0.90	0.63	0.17	0.63	0.59	0.96	0.36	0.95	0.76	0.76	0.83	0.59	0.29	0.61	0.86	1.00	0.85	0.54	0.63	0.25	0.51	0.61	0.50	0.56	0.63	0.25	0.93	0.95	0.72	0.57	0.93	0.72
solid	0.92	0.62	0.92	0.92	0.92	0.83	0.60	0.17	0.47	0.51	0.90	0.58	0.92	0.64	0.64	0.75	0.52	0.30	0.46	0.95	0.85	1.00	0.35	0.65	0.26	0.31	0.63	0.42	0.58	0.65	0.26	0.90	0.92	0.71	0.58	0.90	0.62
human	0.55	0.54	0.55	0.55	0.55	0.61	0.39	0.29	0.62	0.46	0.56	0.26	0.55	0.59	0.59	0.57	0.72	0.17	0.70	0.26	0.54	0.35	1.00	0.22	0.00	0.96	0.30	0.62	0.09	0.22	0.00	0.56	0.55	0.43	0.30	0.56	0.52
gas	0.64	0.52	0.64	0.64	0.64	0.62	0.47	0.00	0.27	0.33	0.65	0.15	0.64	0.41	0.41	0.59	0.38	0.14	0.49	0.59	0.63	0.65	0.22	1.00	0.13	0.23	0.58	0.27	0.15	1.00	0.13	0.65	0.64	0.48	0.58	0.65	0.50
liquid	0.32	0.42	0.32	0.32	0.32	0.27	0.27	0.00	0.00	0.00	0.32	0.30	0.32	0.10	0.10	0.00	0.00	0.00	0.24	0.27	0.25	0.26	0.00	0.13	1.00	0.00	0.26	0.27	0.00	0.13	1.00	0.32	0.32	0.32	0.26	0.32	0.00
human E	0.53	0.50	0.53	0.53	0.53	0.59	0.40	0.30	0.64	0.48	0.54	0.27	0.53	0.62	0.62	0.53	0.75	0.17	0.73	0.22	0.51	0.31	0.96	0.23	0.00	1.00	0.31	0.56	0.09	0.23	0.00	0.54	0.53	0.39	0.31	0.54	0.54
rot ME	0.62	0.54	0.62	0.62	0.62	0.68	0.28	0.26	0.48	0.48	0.63	0.39	0.62	0.47	0.47	0.61	0.52	0.30	0.56	0.61	0.61	0.63	0.30	0.58	0.26	0.31	1.00	0.35	0.00	0.58	0.26	0.63	0.62	0.61	0.53	0.63	0.58
trans ME	0.60	0.61	0.60	0.60	0.60	0.52	0.21	0.27	0.36	0.36	0.56	0.56	0.60	0.49	0.49	0.52	0.53	0.15	0.78	0.34	0.50	0.42	0.62	0.27	0.27	0.56	0.35	1.00	0.00	0.27	0.27	0.61	0.60	0.46	0.41	0.61	0.42
vib ME	0.53	0.06	0.53	0.53	0.53	0.43	0.40	0.00	0.32	0.32	0.54	0.18	0.53	0.43	0.43	0.41	0.15	0.00	0.00	0.61	0.56	0.58	0.09	0.15	0.00	0.09	0.00	0.00	1.00	0.15	0.00	0.49	0.53	0.45	0.00	0.49	0.40
pneu E	0.64	0.52	0.64	0.64	0.64	0.62	0.47	0.00	0.27	0.33	0.65	0.15	0.64	0.41	0.41	0.59	0.38	0.14	0.49	0.59	0.63	0.65	0.22	1.00	0.13	0.23	0.58	0.27	0.15	1.00	0.13	0.65	0.64	0.48	0.58	0.65	0.50
hyd E	0.32	0.42	0.32	0.32	0.32	0.27	0.27	0.00	0.00	0.00	0.32	0.30	0.32	0.10	0.10	0.00	0.00	0.00	0.24	0.27	0.25	0.26	0.00	0.13	1.00	0.00	0.26	0.27	0.00	0.13	1.00	0.32	0.32	0.32	0.26	0.32	0.00
light E	0.99	0.74	0.99	0.99	0.99	0.89	0.61	0.16	0.61	0.61	0.97	0.54	0.99	0.76	0.76	0.83	0.65	0.28	0.67	0.86	0.93	0.90	0.56	0.65	0.32	0.54	0.63	0.61	0.49	0.65	0.32	1.00	0.99	0.76	0.63	1.00	0.73
EE	1.00	0.77	1.00	1.00	1.00	0.91	0.60	0.16	0.60	0.60	0.99	0.53	1.00	0.78	0.78	0.82	0.64	0.28	0.66	0.88	0.95	0.92	0.55	0.64	0.32	0.53	0.62	0.60	0.53	0.64	0.32	0.99	1.00	0.75	0.62	0.99	0.72
mag E	0.75	0.44	0.75	0.75	0.75	0.75	0.46	0.00	0.51	0.40	0.76	0.39	0.75	0.57	0.57	0.67	0.48	0.00	0.57	0.66	0.72	0.71	0.43	0.48	0.32	0.39	0.61	0.46	0.45	0.48	0.32	0.76	0.75	1.00	0.22	0.76	0.57
therm E	0.62	0.65	0.62	0.62	0.62	0.55	0.48	0.26	0.48	0.55	0.59	0.39	0.62	0.47	0.47	0.51	0.58	0.45	0.38	0.57	0.57	0.58	0.30	0.58	0.26	0.31	0.53	0.41	0.00	0.58	0.26	0.63	0.62	0.22	1.00	0.63	0.52
status	0.99	0.74	0.99	0.99	0.99	0.89	0.61	0.16	0.61	0.61	0.97	0.54	0.99	0.76	0.76	0.83	0.65	0.28	0.67	0.86	0.93	0.90	0.56	0.65	0.32	0.54	0.63	0.61	0.49	0.65	0.32	1.00	0.99	0.76	0.63	1.00	0.73
control	0.72	0.51	0.72	0.72	0.72	0.71	0.42	0.22	0.84	0.84	0.73	0.34	0.72	0.68	0.68	0.88	0.78	0.26	0.54	0.57	0.72	0.62	0.52	0.50	0.00	0.54	0.58	0.42	0.40	0.50	0.00	0.73	0.72	0.57	0.52	0.73	1.00

APPENDIX C: FUNCTIONAL MODELS

SEIKO KINETIC WRISTWATCH



SHOE-MOUNTED PIEZOELECTRIC HARVESTER



ENVIRO-ENERGIES MAGLEV VERTICAL-AXIS WIND TURBINE