

## Human-powered small-scale generation system for a sustainable dance club

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# Human-Powered Small-Scale Generation System for a Sustainable Dance Club

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**Abstract**—Most human powered energy harvesting systems are used to power ubiquitously deployed sensor networks and mobile electronics. These systems scavenge power from human activity or derive limited energy from ambient heat, light, or vibrations. In most of these conventional methods users must focus their attention on power generation at the expense of other activities. However, for sustainable electrical power generation, energy could be harvested from everyday activities such as walking, running or even dancing. In this paper systems are analyzed that use human power by walking, or running, where an alternative system has been designed and implemented that generates energy from people dancing in a club environment. It will be shown that power's exceeding walking can be extracted from the system, i.e., maximum 80-100 W or an average of 20-30 W over a time period of 10 s.

## I. INTRODUCTION

Humans are a rich source of energy. An average-sized person stores as much energy in fat as a 1000-kg battery [1]. People use muscle to convert this stored chemical energy into positive mechanical work with peak efficiencies of about 25%. This work can be performed at a high rate, with 100 W easily sustainable [2]. Many devices take advantage of human power capacity to produce electricity, including hand-crank generators as well as wind-up flashlights, radios, and mobile phone chargers [3]. In most of these conventional methods users must focus their attention on power generation at the expense of other activities, typically resulting in short burst of generation. For electrical power generation over longer durations, it would be desirable to harvest energy from everyday activities such as walking, running, cycling or even dancing. However, to produce substantial energy from these activities is not trivial.

Recently, the research on energy harvesting has focused on generating electrical power from the shoe sole, with the best devices generating around 0.8 W [3]. Alternatively, a spring-loaded backpack [4] has harnesses approximately 7.4 W of power during fast walking using the vertical oscillations of a 38 kg load. While the backpack does generate significant power levels, the additional degree of freedom provided to the load could impair the user's dexterity and lead to increased fatigue. For harvesting human energy in a club environment this would significantly impair comfort, and since in this case the person is situated at the same position, a non-mobile system has been created to convert the human dancing



(a)



(b)

Fig. 1. Sustainable dance floor at the sustainable club Watt in Rotterdam, The Netherlands [5].

motion into electrical energy. As such, a system has been researched that generates energy from human dancing in a club environment and directly powers LED lighting show situated on the top of the floor tile or around the dancing floor (Fig. 1).

## II. MOTIVATION FOR A SUSTAINABLE DANCE CLUB

Greener clubbing will obviously not solve the problem of rising greenhouse gas emissions, where clubs, with their woofers and strobes, are large electricity consumers and un-

likely to ever be carbon neutral. The European Union and United Nations have said that the greenhouse gases should at least be reduced by 20 percent by 2020 with a share of 20 % of renewable energy generation to prevent dangerous global warming [6]. Most of that reduction has to come from large changes, e.g. closing coal-fired plants and improved protection of rain forests. However, it is also necessary to investigate gains that can come from doing the things everyone does now, but in ways that are a bit more efficient and environmentally friendly.

As such, the environmental issues have even reached the clubbing scene, where in Rotterdam a sustainable dance club, as shown in Fig. 2, has been established [5]. An average size club with around 200,000 visitors on a yearly basis uses around 430 kWh (50 % for lighting, 20 % for heating, 15 % for sound systems and 10 % for cooling). Next to that 10 million liter of water is flushed and 136,000 kg of waste is created. The club has taken many measures to become sustainable (i.e. reducing the energy consumption by: electricity 30 %, water 50 % and waste 50 %), where the largest energy reduction has been achieved by using LEDs, rainwater, smart cooling systems, etc. In addition to the energy savings, general public awareness needed to be introduced, which could be achieved by visualizing "power from the people" to the clubbing public. This need for visualization was one of the drives to create a sustainable dance floor. In addition to awareness, also energy consumption for lighting has been reduced, since the energy harvested during dancing is directly used in the top part of the tile to power the light show in and around the floor. As such, when young people start to understand what energy comprehends and the scarcity of energy, they will try to treat it with much more care. The dance floor consists of individual modules (or tiles) separated in two parts: energy harvesting and lighting. In future larger systems, besides lighting the top of the modules, the human powered electrical energy will also be used for additional lighting, sound and disc-jockey apparatus.

### III. HARVESTING ENERGY FROM PEOPLE

As sustainable living gets an increasing foothold in peoples lives, unobtrusively tapping some fraction of energy available from human activity has recently gained in popularity. In the last decades, energy harvesting has grown from long-established concepts into devices, in general, used for powering ubiquitously deployed sensor networks and/or mobile electronics [7]. Recent developments in the field have led to the design of a number of mechanisms that can be used to generate electrical energy from a variety of sources including thermal, solar, strain, inertia, etc. The clubbing experience application considered in this paper requires a power level of a couple of watts to power a LED lighting show. In general, solar cells (sometimes combined with wind power) are the most commonly used devices to provide the energy generation, however, this is an unfeasible solution in a club environment. Hence, when the only available energy sources are dancing (or jumping) people, only a few sources of power remain, respectively human heat or vibrations. In indoor



(a)



(b)

Fig. 2. Power from dancing people at Watt-a-party in the Congress station, Brussels, 4th of December 2008 [5].

applications, thermoelectric converters on the human skin can provide more power per square centimeter than solar cells, particularly in mainly adverse illumination conditions such as clubs [8]. Alternatively (or complementary), vibrations could be harvested provided that parasitic effects, which disrupt the clubbers dancing experience, are minimized.

#### A. Thermoelectric

Objects (or environments) at different temperatures offer the opportunity for energy harvesting via heat transfer. To enable this, a basic thermoelectric conversion unit can be used, which consists of two different semiconducting materials that are connected together as a thermocouple. In general, thermoelectric devices are modules constructed from a number of these thermocouples, hence in effect, heat drives an electrical current used to generate power ( $20\mu\text{W}/\text{cm}^2$  for a human environment [8]). Considering the high reliability, small size and no noise, thermoelectric technology is highly competitive. However, the relatively low efficiency means that large scale use of thermoelectrics will remain limited to applications served poorly or not at all by existing technology [9]. Therefore, harvesting this energy from warm blooded animals (including humans) using thermoelectric conversion can only be a feasible solution to provide power autonomy for miniaturized and/or wearable electronic products operating at very low power, e.g. watches [10]. Further, also in medical, automotive and industrial environments, compact and reliable self-powered sensor devices could be very feasible solutions



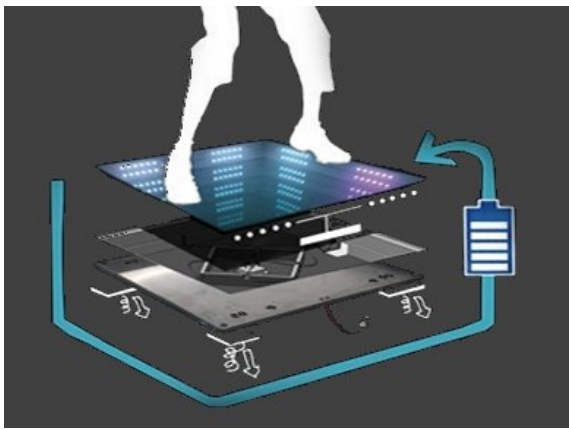


Fig. 3. Artist impression of a single dance floor module.

to replace wired counterparts that feature huge amounts of corroding wires [11]. Accordingly, thermoelectric generators can deliver significant energy levels with high-temperature sources (i.e. a hot exhaust pipe), but are much more limited for temperate environments or wearable applications. Therefore, we have focussed mainly on harvesting the energy from vibrations as will be discussed in the next section.

### B. Vibration

During dancing, the environment does no work on the body, and *visa versa*, humans do no work on the environment. Rather, almost all of the mechanical work is generated and dissipated inside the body [12]. This makes it exceedingly difficult to capture mechanical energy to drive an electrical energy conversion apparatus, because the device would need to be either surgically placed within the body or attached to the outside of the body (such as an exoskeleton on the knee [13]). However, these exoskeletons certainly would impede the maneuverability and comfort of dancing persons.

An alternative solution to harvest electrical energy available from human power, investigated already for centuries, is the self-winding wristwatch. This system uses the natural wave of the arms of walking people to power wrist-mounted platforms. As such, a modern self-winding wristwatch contains a rotary proof mass mounted off-center on a spindle, which reacts inertially. This is consequently used to directly spin an electrical generator or alternatively stores the energy in a spring, where after it is transferred to the generator at its optimal rate [14]. Alternatively these systems can also be used in, e.g. a flashlight, where they produce around 200 mW under normal motion when the hand is shaken at approximately 200 cycles/minute [3], [15]. However, also these systems impede the comfort of dancing people especially if larger amounts of energy need to be harvested.

Recently, the research on energy harvesting has focused on generating electrical power parasitically while walking from the shoe sole, with the best devices generating around 0.8 W [16]. In general, these systems use the pressure of the heel to, for example, spin a flywheel attached to the generator

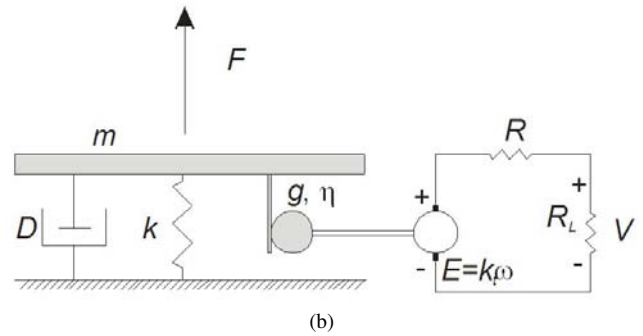
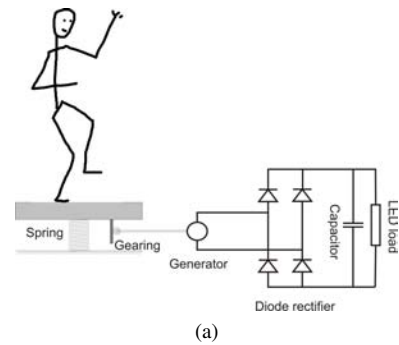


Fig. 4. Equivalent dance floor model of the energy harvesting illustrating (a) the simple mechanical and electrical model (b) the schematic of the energy harvesting part.

and extract the power from the pressure of the heel during walking. However, these systems are difficult to integrate reliably into standard footwear [3]. Therefore, also systems that use the bending strain of the shoe sole are investigated that generate electrical charge by laminate of piezo films, where [17] calculated that approximately 67 W of power is lost during walking and that a piezoelectric device mounted inside a shoe with a conversion efficiency of 12.5 % could achieve 8.4 W of power. Although it needs noting that most current implemented systems generate power levels in the order of milliwatts to watts [18]. This clearly gives relatively low efficiencies and therefore alternatives to piezo solutions were investigated.

The most attractive available alternative to harvest substantial energy levels from dancing people is a spring-loaded backpack, which converts mechanical energy from the vertical movement of carried loads to electricity. This system harnessed approximately 7.4 W of peak power during fast walking using the vertical oscillations of a 38 kg load [4]. While the backpack does generate the necessary power levels for the light show, the additional degree of freedom provided to the load would impair the user and lead to increased fatigue. Related to harvesting human energy in a club environment this would significantly impair on the clubber experience. As such, in a clubbing environment, the human is based at the same position and non-mobile systems could be a suitable alternative to transfer the human dancing motion into electrical energy. This energy should then be directly used to power the LED lighting show situated on the top of tile or around the floor to further enhance the systems utilization, as shown in Fig. 3.

#### IV. MODEL OF THE HARVESTING PART OF THE TILE

To study the physical behavior of the energy generation system of the dance floor, as shown in Fig. 4a, rather than using finite-element methods coupling together with Maxwell's equations and dynamics of the structure, a simplified circuital approach was selected. This does allow for the time and frequency domain analyses of the whole system and is preferred due to its simplicity and ease of parameter changes without significant computational overhead. Consequently, using this model to understand the basic characteristics of the components, many of the performance limitations of the system will be remedied and a system optimization can be explored. The load of the harvesting part of the dance floor is the LED lighting show in the top part of the tile. This electrical load consists of arrays of LED devices, which can be either voltage or current source-supplied. In order to obtain linear control of the light intensity, a voltage regulated dimming scheme for the LEDs is adopted. As such, a simple down converter has been implemented, since the brightness and power consumption of LEDs are directly related to their forward current. This converter has been simplified in the equivalent schematic to a load resistor connected in parallel to the storage capacitor.

The simplified harvesting model, as shown in Fig. 4b, consists of a tile suspended by springs and modeled by a simplified mass,  $m$ , mechanical springs combined to a single spring coefficient  $k$  and a damper  $D$ . In this system, the linear vertical motion of the moving part of the tile is converted to rotary motion by a gear with gear ratio  $g$  and efficiency  $\eta$ , where the energy is harvested with a brushed DC generator. This DC machine is modeled by its motor constant,  $K_t$ , and armature resistance,  $R$ , with a load resistance,  $R_L$ . As such, the armature winding inductance ( $L = 1.67 \text{ mH}$ ) has been neglected. This gives that the state-space equivalent model of the system is given by:

$$\begin{bmatrix} \dot{x} \\ \ddot{x} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \frac{k}{m} & -\frac{D}{m} - \frac{(K_t g)^2}{m \eta (R + R_L)} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \ddot{x} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix} \quad (1)$$

and

$$V = \begin{bmatrix} 0 & \frac{K_t g R_L}{(R + R_L)} \end{bmatrix} \begin{bmatrix} \dot{x} \\ \ddot{x} \end{bmatrix}, \quad (2)$$

where  $x$  is the position and  $V$  the voltage across the load resistance.

Proper matching of loads to the generating system is required for optimum system sizing and higher utilization of the energy. In this respect measures have been introduced for the quality of matching based on the energy consumed by the load to the amount of maximum harvested energy. This implies that the optimum load parameters have been determined with the objective to maximize the amount of harvested energy. In order to generalize the analysis, a mass of 70-100 kg is assumed that combines both the mass of the person and lighting part of the dance floor. An analysis for the matching factor around the optimum has been studied, where Fig. 5 demonstrates that the

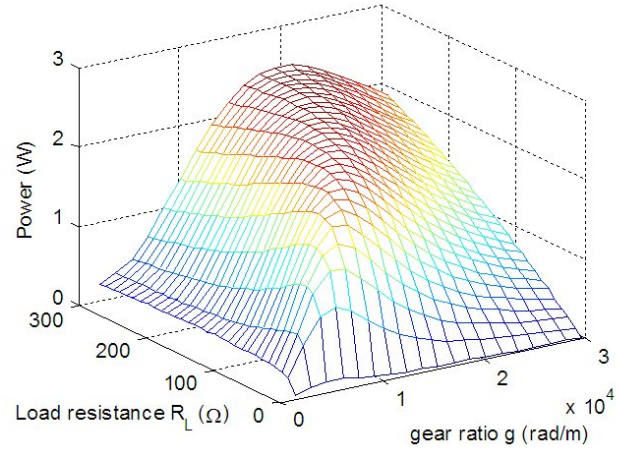
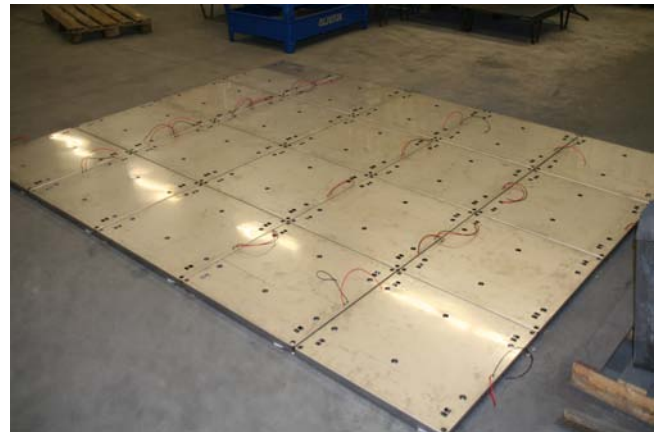
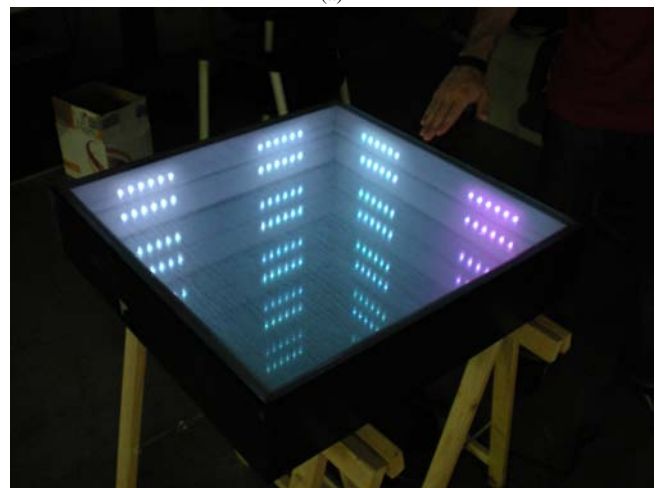


Fig. 5. Output power as function of the load and gear ratio.



(a)



(b)

Fig. 6. Dance floor modules (a) bottom part consisting of interconnected harvesting tiles (b) top part that features the light show [19].

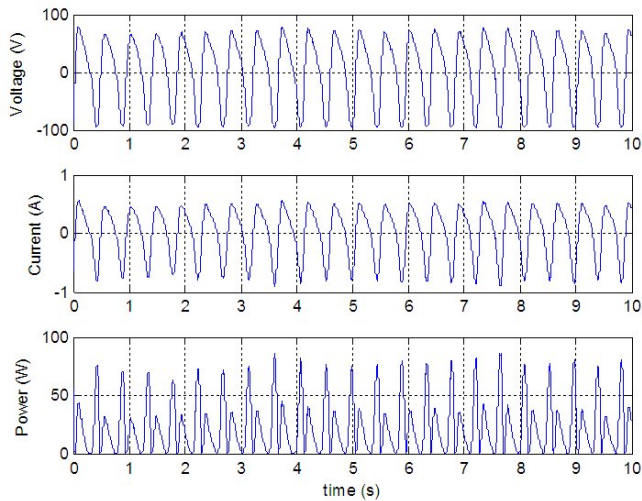


Fig. 7. Measured waveforms from the harvesting part of the dance floor without rectifier (mean power is 24.1 W).

output power strongly depends on the load resistance and gear ratio. For the system a gear ratio of  $g = 22000 \text{ rad/m}$  and a load resistance of  $R_L = 150 \Omega$  is selected.

### V. PROTOTYPE

In order to validate the design and analysis techniques which have been developed, prototypes have been created in order to perform the measurements. The electromechanics and embedded electronics are integrated into a single module to minimize the height of the harvesting part of the tile. The dancing feeling can be manually be adjusted by varying the preloading of the spring. A further important parameter is the integration of torque compensation into the design, which does occur when the dancing people are exciting the tile off-center. The stainless steel tile modules (RVS316L) of  $65 \times 65 \times 5 \text{ cm}$  with a maximum movement of 1 cm, as shown in Fig. 6a, has been used to measure the amount of harvested energy, as will be discussed in the next Section.

To create a clubbing experience, the top part of the tile ( $65 \times 65 \times 14.5 \text{ cm}$ ) has an integrated light show that visualizes the energy generation. To create a very sustainable solution with minimized energy use, the lighting tile (combination of reused PVC, mirrors and hardened glass) has been equipped with a smart mirror construction combined with LED arrays on the sides to maximize the use of the light. Variable virtual depth can be created by varying the light intensity, to visualize a single LED array up to twenty slowly fading arrays, as shown in Fig. 6b [19]. In this respect, both the harvesting and the lighting part of the tile have many features to account for future developments of the floor, e.g., for implementation of control alternatives to alter the behavior of the dance floor.

### VI. MEASUREMENTS

The measured voltage, current and power waveforms of the dance floor system are shown in Fig. 7, respectively. This shows that energy is both generated when the tile moves

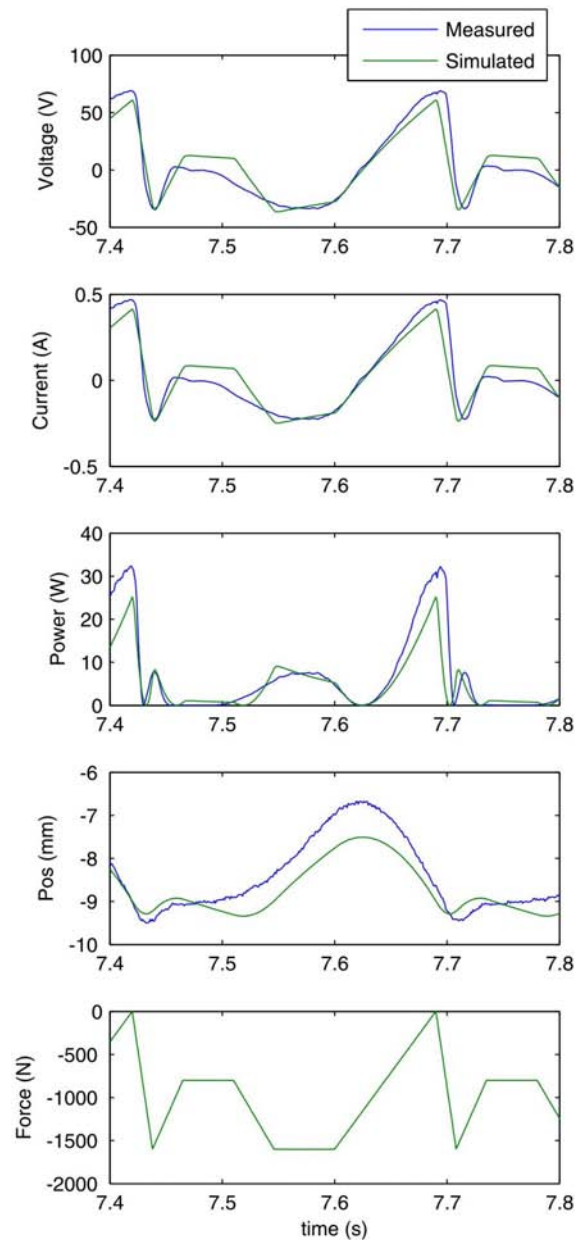


Fig. 8. Average sustainable dancing measurement waveforms from the harvesting part without rectifier (mean power is 4.8 W), which shows output voltage (V), current (A), power (W), relative position (mm) and simulated force input (N).

downwards due to the force applied by the dancer and when the tile moves upwards due to the spring, even when there is no contact with the dancer. The measured maximum average output power indicated about 24.1 W, i.e. without rectifier and averaged over 10 seconds. It needs noting that using different dancers the maximum average power level varied around some 20-30 W, which were easily sustainable for extended periods of some minutes. In these measurements, during short intervals, the harvested output power peaks at approximately 60-100 W (some additional measurements even showed peak



power levels of over 100 W). When using a very standard low cost diode rectifier and a large capacitor, this maximum average output power reduces to 22.4 W.

Fig. 8 compares the predicted and measured output waveforms of an almost continuously sustainable input for a single dancing person, respectively with a harvested energy of 4.8 W average power and a peak power of 32 W. This figure clearly shows the agreement of the measured and simulated waveforms. However, it needs noting that the force input of the simulated analysis was adjusted to suit the measured position waveforms, since this provides for a very non-linear input. As such, Fig. 8 also shows the relative input position profile of a dancing person, which has been used to reconstruct the force input to the harvesting tile.

## VII. CONCLUSION

An energy harvesting tile has been created that converts the energy of dancers into electrical energy that powers a light show in the top part of the module or in close proximity to the floor, as shown in Fig. 9. A model of the power generation system that achieves maximum output power from dancing people has been presented. Further, measurements have shown that approximately 20-30 W can be generated for a period of 10 seconds, where peak powers of some 80-100 W are harvested during very short intervals. Although that a single person dancing for extended periods of time would generate average power levels of approximately 2-8 W. Considering these power levels it should be taken into account that a further energy saving is apparent, when comparing this dance floor to grid connected devices, due to the lack of electric transmission losses.

Social and environmental issues are worldwide and will always demand attention. As such, sustainability is more the beginning of a new corporate attitude or lifestyle than a dying trend. Numerous examples exist that companies working on their sustainability are very profitable, e.g., due to loyalty and motivation of employees, loyalty of customers, imagination, innovation, etc. Therefore, in addition to club environments also systems that harvest power from the people are being developed for application within train stations, busy traffic intersections, airports, etc.

## ACKNOWLEDGMENT

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Fig. 9. The energy of dancers has turned into electrical energy that powers a light show within the floor modules or in close proximity to an energy meter.

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