what performers need, when they need it, in the form they need it in, so that they can perform in ways that meet organizational objectives” [16]. The ADAPTS project [4] provides an intelligent, adaptive electronic performance support system for maintaining complex equipment. ADAPTS maintains a dynamic characterization of a technician's knowledge, experience, and preferences in the form of a user model. This model influences the diagnostic strategy, technical information content, and navigation support offered to a technician. ConceptMaps [9] is an example of a knowledge visualization tool that can be combined with recent technology to provide integration between knowledge and information visualizations. Xiahou, Chen, and Huang [19] present a wearable system to support learning and training and operation of maintenance activity in industrial settings. These systems usually include the following feedback components: learning, guidance and tracking, task-structuring support, information support and coaching, knowledge management, communication, and collaboration tools. In the following section we propose enhancing PSS with human behavior sensor data in order to create sensor-based feedback systems applicable at the individual, group and organizational levels.

III. Proposed Scenarios

We have developed a set of tools and methods to automatically capture, measure, and analyze human behavior in organizational settings in order to improve performance and optimize organizational structures and decisions i.e. office layout, team formation, and organizational structure [14]. Our goal is to be able to map behavioral patterns to quantifiable outcomes and provide employees and managers with feedback that allows them to adjust their behavior in order to optimize a desired outcome. Our proposed approach includes the following steps:

1. Capturing the interactions and social behavior of employees, managers, and customers using wearable and/or environmental sensors such as the sociometric badges (figure 1) [14]. Other sources of information that can be incorporated into the system are any form of digital records (i.e. e-mail, chat, phone logs).
2. Performing data mining and pattern recognition to extract meaningful information from these data.
3. Combining the extracted information with performance data (i.e. sales, tasks, timing) and finding relationships between objective measurements and performance outcomes.
4. Generating feedback in the form of graphs, interactive visualizations, reports, or real-time audio-visual feedback for employees, managers and/or customers in order to improve organizational performance and customer satisfaction.
5. Behavior simulation, prediction and modification.
6. Continuous measurement and performance assessment.

Figure 1. The sociometric badge, an example of a sensor-based system that detects individual and social behavior in real-time allowing real-time feedback.

A sensor-based feedback system for organizational computing consists of environmental and wearable sensors, computers, and software that continuously and automatically measure individual and collective patterns of behavior, identifies organizational structures, quantifies group dynamics, and provides feedback to its users. The purpose of such a system is to improve productivity, efficiency, and/or communication patterns within an organization.

A. *Web-based individual feedback*

Performance dashboards are becoming increasingly popular, but how to structure this feedback, particularly when it comes from sensor data, is an unanswered question. We believe that pushing individual level feedback onto the web will allow users that are increasingly more familiar with social networking sites, wikis, and other online media to interact with their data in a much richer way. This approach also dovetails nicely with recent systems that create corporate networking sites, such as Beehive [7], where users are already used to managing privacy settings and the like. Naturally this becomes even more crucial when dealing with detailed sensor data.

Choosing levels of abstraction with which to show individual feedback is also crucial. One has to balance the desire to show unfiltered data with the knowledge that interpretation of such data is difficult at best and quite prone to error. When giving people feedback on their movement patterns, for example, rather than just showing the energy of movement, tying this data to physical or psychological states using easy to understand icons would be preferable. Interestingly, SNIF, which sells dog tag sensors for pet use, employs exactly this approach for feedback on dog behavior [15]. By providing individual and social behavioral data to individuals, we aim to help self-assessment and behavior modification which can lead to higher job satisfaction and performance.

B. Group-level feedback

The small group is a vital unit that has to function properly for the success of any organization. Feedback on group dynamics has been proven to help with the performance of small group collaboration. We propose a system to detect group dynamics and provide feedback according to the group's goal. By synchronizing multiple wearers' sociometric data, we are able to get information such as turn taking, influence, body movement mimicry, and similarities in behavior. We then visualize sociometric data to provide feedback on their group dynamics. The feedback is visualized on the mobile phone of each participant. For it to be a persuasive interface, encouraging change in group behavior, visualization should be designed to guide the direction of change.

Laboratory study results of initial prototypes show that sociometric feedback changes groups to have higher interactivity levels and more communication. This effect was stronger for groups collaborating remotely, reducing the dynamical difference between co-located and distributed collaboration [11]. In a different study we found that groups with feedback showed more solo speaking time and less body movement. More interestingly when given feedback on their communication patterns, individuals became more cooperative, increasing the overall performance of the group [12]. These results are promising as they verify that real-time sociometric feedback can indeed change group dynamics and their performance.

C. Organizational-level feedback and Responsive Buildings

1) Organizational Engineering using Social Network Analysis

We have recently deployed our organizational engineering system at a bank's call center, where a group of 80 employees (working in four different teams) and managers used sociometric badges for a month. Daily productivity metrics have been made available to us: number of phone calls handled, average call handle time, speaking time, and system use time, among others. Preliminary results seem to indicate that cohesion in the face-to-face social network (captured with our system's wearable sensors, figure 2) is negatively correlated with the average handle time. This is in agreement with the results obtained by Wu, Waber, Aral, Brynjolfsson, and Pentland [18] and has several implications for the call center's operations. We are currently working on feedback mechanisms to present real-time information to managers and are also preparing general recommendations to improve the performance in the call center. For instance, one possible intervention would be to change the way employee's breaks are currently scheduled. Instead of minimizing the number of people taking a break at the same time (how it is currently done), we are changing the break schedule so that more people working in the same team can take a break at the same time. This would allow members of the teams to form more cohesive ties over time, and allow knowledge sharing, which in turn would lead to a reduction in the average call handle time.

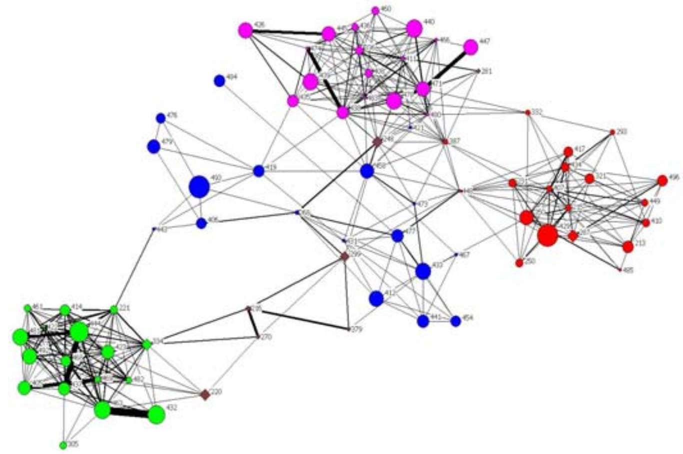

Figure 2. The social network diagram created using sociometric badges. The structure of the diagram reveals the cohesiveness of each team (color coded).

2) Tightening

Social connectors are vital for any social system to thrive [4]. These are the people that make our lives better and help society as a whole by connecting disparate social segments together. Connectors tend to be more productive than non-connectors [1], and in organizations where this skill is recognized and rewarded the organization benefits [5]. But why can't we all be social connectors? What if everyone could tap into the same skills used by these individuals?

Imagine an application that lets people know when their social connections could help their friends. While a natural connector may have picked up on this information, it is a difficult task for most people, who do not have wider knowledge of the structure of the social systems that they inhabit [5]. By creating an *Augmented Social Reality* tool that sent out such notifications we would allow everyone to become a social connector. Naturally, for this approach to work we must first acquire knowledge of who knows whom: the "true" social network. To quantify these ties a wearable sensor such as the sociometric badge is the obvious tool of choice, since it is an accurate and objective measurement device and could be used as an ID replacement in most formal organizations [14].

For two people who have no friends in common to be introduced to each other, introductions must be made through intermediaries. This will create a patchwork of ties that would slowly close the gap between these two users in a process we call tightening. Tightening consists of creating a link between two target users by introducing them to users that they do not have prior ties with and are on the shortest path in the social network between the targets. The new ties formed in this process must bring the targets strictly closer to each other as long as there is not resistance from a user on the shortest path. If a user does not want to be introduced with one of the targets, then we can attempt to circumvent them by taking the next shortest path through the network. Both targets connect to each other when they have a common acquaintance who introduces them.

3) *Responsive Buildings*

Another method that can be utilized is an approach that we call *Responsive Buildings*. Today, buildings and office layouts change at a glacial pace. Although companies build new corporate headquarters that they expect to occupy for 50 years, they design these buildings with fixed walls and doors to deal with the organization as it exists today. By using sensors we can now think of modifying these structures with knowledge of the interaction patterns occurring within the building in real-time according to the preferences of the occupants. This contrasts starkly with the more common approach in architecture of having doors and walls respond without concern for the larger social system that occupies the workplace.

Office layout is one of the primary driving forces behind interactions in the workplace. People talk much more to people who are close to them, and if someone has to go through more effort to interact, the probability that they will interact if they do not know each other beforehand degrades. Therefore we can attempt to influence interaction patterns much more subtly using architecture. We could encourage or discourage interaction by making robotic cubicle walls that we could programmatically lower or raise based on people's preferences. We could also do this using window shades as cubicle walls, again raising or lowering them based on preferences. To influence communication patterns across entire groups, we could program movable partitions that would place themselves in the space between groups to create more enclosed spaces.

IV. Conclusions

Radical change is needed in today's organizations. While e-mail, instant messaging, wikis, prediction markets, and the like have proliferated across myriad sectors, the fundamental practice of management has failed to keep pace. Sensors and sensor-based feedback are poised to help create the change necessary to deal with these problems. At the individual level we can begin to help people understand how their normal behaviors can have startling effects on their job performance and happiness. We can use sensors to tune group dynamics so meetings are more in line with group goals and avoid common psychological pitfalls. Finally, we can harness these massive data streams to give people an enhanced sense of their organization's social environment, shifting focus from formal ties to the arguably more important informal ones. These changes may even manifest themselves in the physical architecture of organizational spaces, creating *Responsive Buildings*. The opportunities are even more numerous than was described here, but we hope this paper will direct future research towards these promising avenues, and help create *Sensible Organizations*.

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